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TACELIS RAM EVALUATION.(U)

APR 79 N K MATTHIS, T J MORIN, W E THOMPSON DAEA18-72-A-0005

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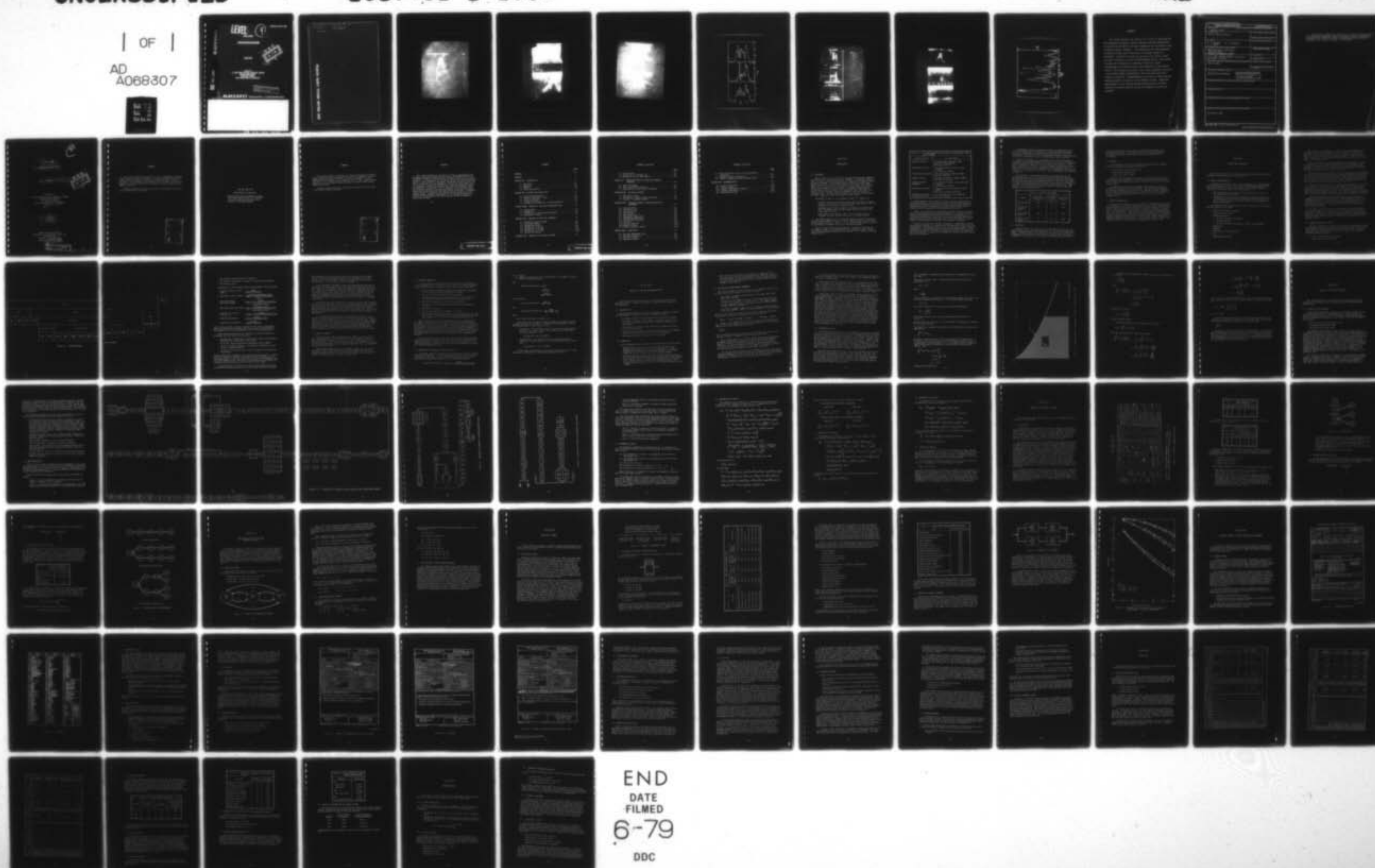

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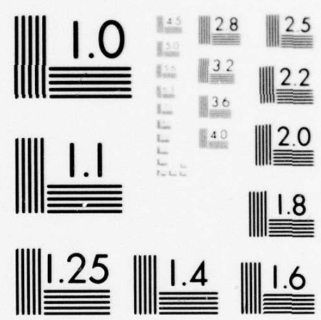

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FINAL REPORT

TACELIS RAM EVALUATION

April 1979

Prepared for
U.S. ARMY SIGNALS WARFARE LABORATORY, ERADCOM
VINT HILL FARMS STATION
WARRENTON, VIRGINIA
under Contract DAEA18-72-A-0005-D302

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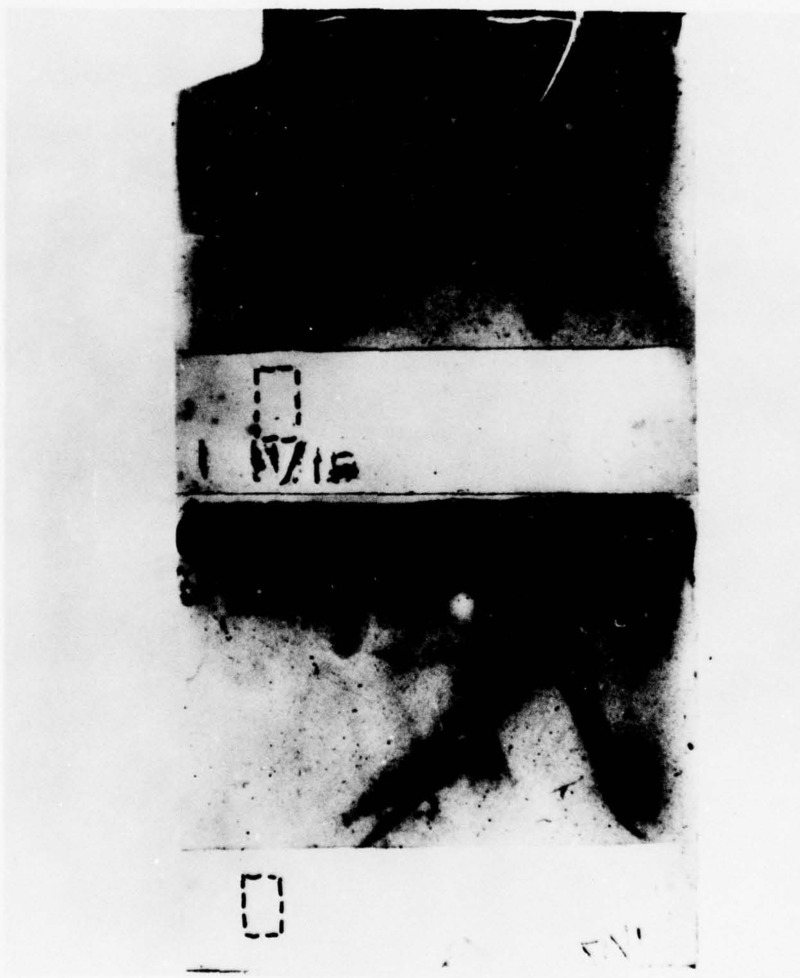


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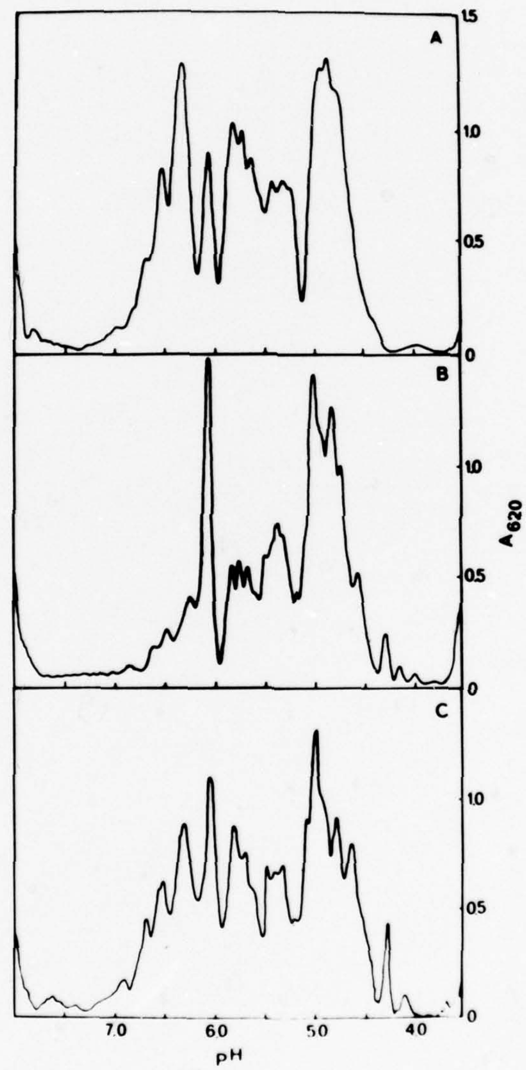
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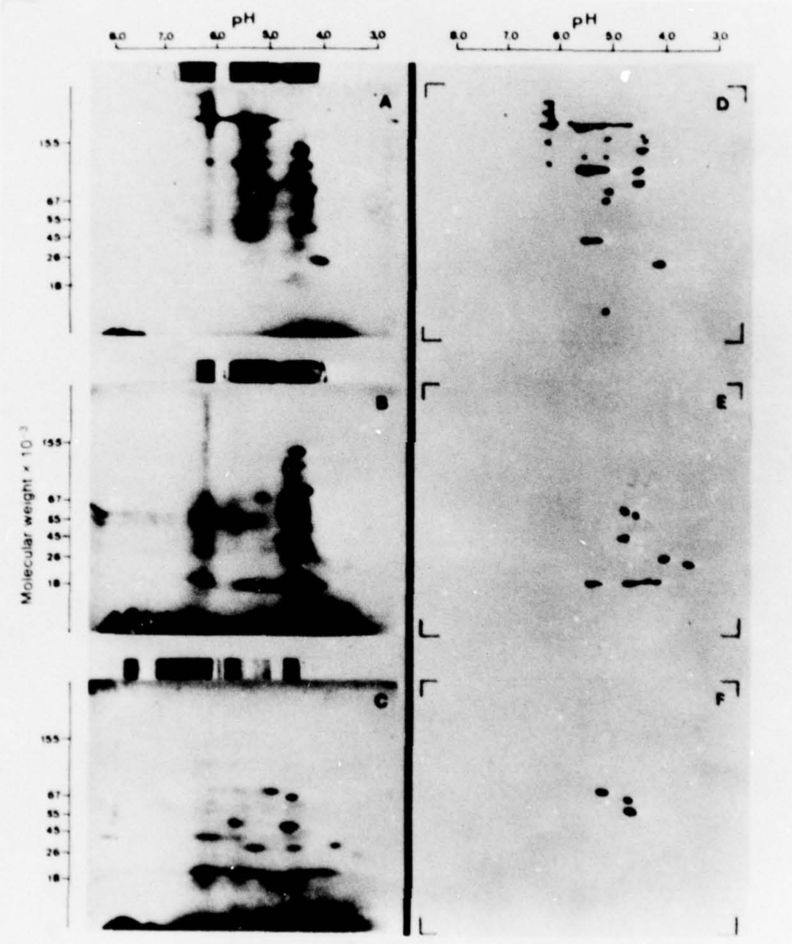
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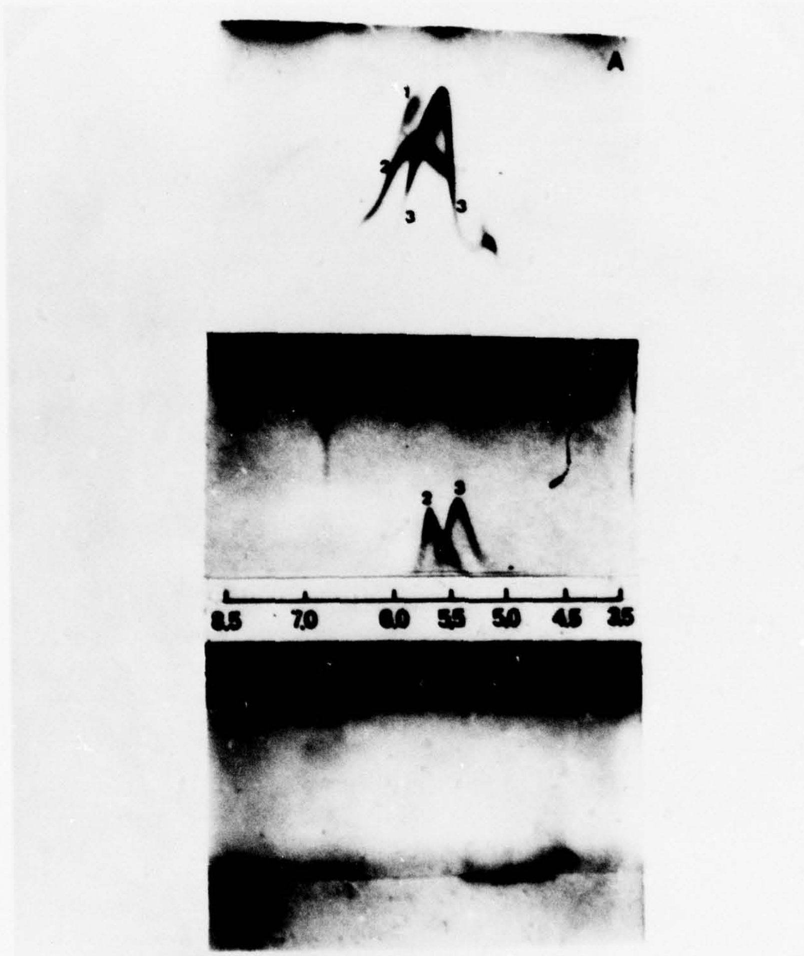
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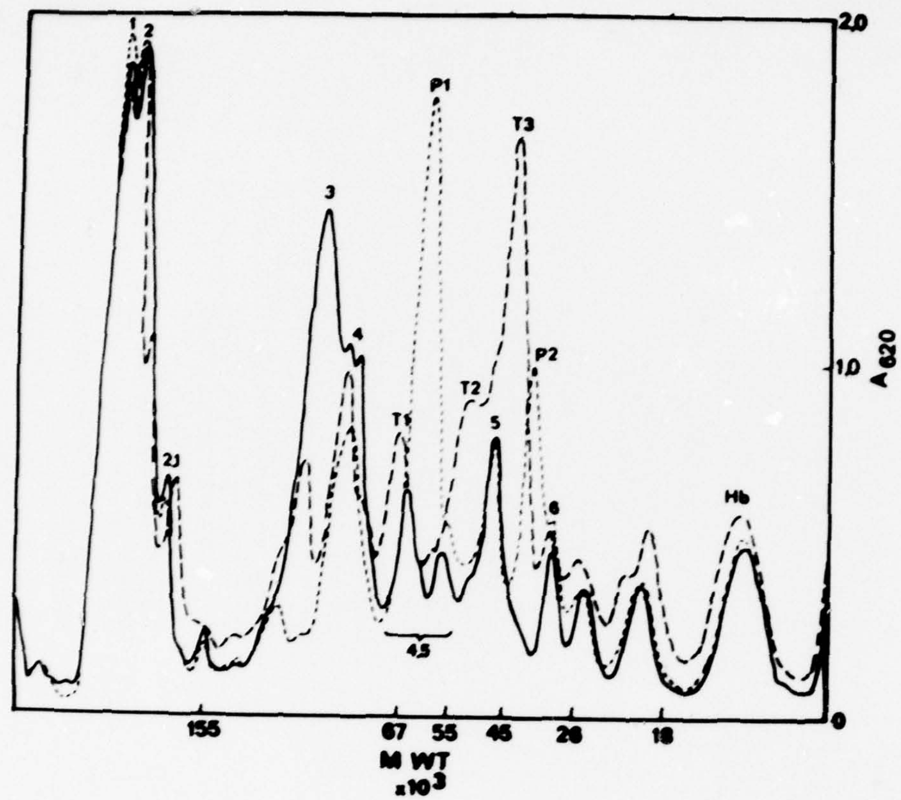
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ABSTRACT

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1. REPORT NUMBER 1087-01-1-1905	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) Tacelis Ram Evaluation		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(*s*) N. K. Matthis W. E. Thompson T. J. Morin		8. CONTRACT OR GRANT NUMBER(*s*)
9. PERFORMING ORGANIZATION NAME AND ADDRESS ARINC Research Corporation 2551 Riva Road Annapolis, Maryland 21401		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Signals Warfare Laboratory Warrenton, Virginia		12. REPORT DATE
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*) same as above		15. SECURITY CLASS. (*of this report*)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

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(11) April 1979 (12) 76p.

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U.S. Army Signals Warfare Laboratory, ERADCOM
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by

(10) N.K. Matthis,
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Publication 1087-01-1-1905

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The U.S. Army is in the process of developing the Tactical Communications and Emitter Identification System (TACELIS). The TACELIS system is part of a larger intelligence-gathering and communications-jamming complex designated TACOM-EW. The TACOM-EW system is deployed in several Army vehicles and shelters near the Forward Edge of the Battle Area (FEBA) to gather intelligence from the interception of enemy communications and to control active jamming of these signals. The TACELIS system hardware includes more than 130 different Line Replaceable Unit (LRU) types, consisting of both Government Furnished Equipments (GFE) and contractor-developed items. Several different software applications packages hosted by various computers control the operation of the system.

The TACELIS system, at full equipment strength, is composed of:

- A Control and Processing Center (CPC), which includes 23 operator stations, each served by a Cathode Ray Tube (CRT) display. The CPC equipment is contained in four large vans.
- Two Remote Master Stations (RMSs), each deploying sheltered electronic equipment and an antenna support vehicle carried in four trucks and a cargo van.
- Eight Remote Slave Stations (RSSs), each including electronic equipment and other hardware sheltered in a tracked vehicle.

The TACELIS communications intelligence-gathering system is currently undergoing developmental testing at the U.S. Army Electronic Proving Ground at Fort Huachuca, Arizona. Table 1-1 lists the seven Army agencies involved in the materiel development process for the TACELIS system.

The U.S. Army Signals Warfare Laboratory, as Materiel Developer for the TACELIS system, has placed ARINC Research Corporation under contract to review the hardware maintenance data from the first 11 months of developmental testing.

Table 1-1. U.S. ARMY AGENCIES PARTICIPATING IN ACQUISITION OF THE TACELIS SYSTEM	
Agency Function	U.S. Army Agency
Materiel Developer	Signals Warfare Laboratory (SWL) Vint Hill Farms Station Warrenton, Virginia
Developmental Tester	U.S. Army Electronic Proving Ground (USAEPG) Fort Huachuca, Arizona
Developmental Evaluator	Test and Evaluation Command (TECOM) Aberdeen, Maryland
Combat Developer	Training and Doctrine Command (TRADOC) Fort Monroe, Virginia
Combat Developer/ Proponent	U.S. Army Intelligence Center and School (USAICS) Fort Huachuca, Arizona
Operational Evaluator	Operational Test and Evaluation Agency (OTEA) Bailey's Cross Roads, Virginia
RAM/Logistics Advisor to Combat Developer	U.S. Army Logistics Center (USALOGC) Fort Lee, Virginia

Army Regulation 70-10 states the concept, assigns responsibilities, establishes policies, and prescribes procedures for test and evaluation, and provides information for use at decision reviews during the materiel acquisition process, in implementation of DoD Directive 5000.3 and in consonance with the provisions of Army Regulation No. 1000-1.

Testing is conducted (1) to demonstrate how well the materiel system meets its technical and operational requirements; (2) to provide data for assessing developmental and operational risk in decision-making; (3) to verify that the technical, operational, and support problems identified in previous testing have been corrected; and (4) to ensure that all critical issues to be resolved by testing have been adequately considered.

Testing is divided into two basic categories -- developmental testing and operational testing -- as described in Army Regulations 1000-1 and 71-3, respectively. Developmental testing is the testing and evaluation conducted to demonstrate that the engineering design and development process is complete, that the design risks have been minimized, and that the system will meet specifications -- as well as to estimate the system's military utility when it is introduced.

Developmental testing is planned, conducted, and monitored by the Materiel Developer and is accomplished in a proving ground environment. It includes engineering design testing and human factors testing to demonstrate a satisfactory technical man-machine interface, using qualified and experienced operators, crews, and maintenance support personnel.

As Materiel Developer for the TACELIS system, the Signals Warfare Laboratory is tasked with demonstrating that the Reliability, Availability, and Maintainability (RAM) goals for the system can be achieved. These goals are defined in terms of the total system and the three major assemblies constituting the system. Quantitative RAM requirements for the TACELIS system are specified in Appendix A of the TACELIS Purchase Description AS-011-72, Revision A, 1 June 1972. These requirements are presented in Table 1-2.

The data base for determining whether the assigned goals can be achieved consists, in part, of detailed Maintenance Request forms that are generated for every controlled maintenance action and for each modification incorporated during developmental testing. Data from these forms are compiled on Equipment Performance Report forms, which are evaluated at a scoring conference attended by the participating Army agencies. RAM statistics are derived from the evaluated data in accordance with Army Regulation 702-3 and MIL-STD-721B.

Table 1-2. TACELIS REQUIREMENTS

Assembly	Mean Time Between Failures (Hours)	Mean Time to Repair (Hours)	Availability (Inherent)
Total System	100	100	.9680
Control and Processing Center	400	60	.9975
Remote Master Station	200	100	.9825
Remote Slave Station	200	100	.9825

1.2 OBJECTIVE

The objective of this study is to calculate RAM statistics for the total TACELIS system, its major assemblies, and its Line Replaceable Units (LRUs). Candidate LRUs for increasing system reliability are identified. Changes to improve reliability documentation during further testing are recommended. In addition, certain analytic techniques that may extend the

statistical predictions and assessments of TACELIS RAM performance are developed and evaluated. These same techniques will provide the means for identifying critical system deficiencies and evaluating design alternatives.

1.3 APPROACH

For developmental testing of the TACELIS system, the major assembly types were deployed in the following quantities:

- Control and Processing Center (CPC) 1
- Remote Master Station (RMS) 2
- Remote Slave Station (RSS) 4

Approximately 600 Equipment Performance Report forms had already been generated during developmental testing of the TACELIS system at the start of this study. This bounded set is the data base for the results presented in this report.

The RAM values associated with TACELIS system elements have been developed from an analysis of the data base. Reliability block diagrams for the major assemblies have been used for computing assembly reliability and for studying assembly sensitivity to selected units. The reliability of the total system has been studied on the basis of a time history of assembly failures.

1.4 REPORT ORGANIZATION

This report is organized so that the analysis of RAM statistics begins at the simplest level, the Line Replaceable Units; increases in complexity with an analysis of the major assemblies; and finally, deals with the total system. The concepts and definitions to be used are described in Chapter Two. In Chapters Three, Four, and Five, the RAM analysis proceeds through the three system levels. Chapter Six presents a method for quantitatively discussing system states having degraded operational capability. Reliability growth is analyzed in Chapter Seven. Chapter Eight suggests changes for maximizing RAM analysis opportunities during system testing. Chapters Nine and Ten present the conclusions and recommendations, respectively.

CHAPTER TWO

CONCEPTS AND DEFINITIONS

This chapter presents the conceptual framework within which reliability parameters are defined as used in this report.

2.1 AREAS OF RESPONSIBILITY

All agencies that participate in the development, use, and maintenance of a system contribute to the effectiveness of the deployed system. Therefore, two steps must be taken to give numerical descriptions and make quantitative predictions about system effectiveness.

- The responsibilities of each participating agency with respect to the system must be identified.
- Parameters that can be derived from data describing system response in operational situations must be defined to serve as figures of merit for the success of participating agencies in contributing to system effectiveness.

The following areas of responsibility may be identified in the development and operation of a system:

- Definition of system requirements
- Technical specifications
- Engineering design
    - To meet functional requirements
    - To facilitate use
    - To allow convenient maintenance, repair, and replacement
- Manufacture
- Assembly
- Definition of logistic support
- Use
- Maintenance and repair

Meeting these responsibilities is essential to the deployment of an effective system. The requirements for the system must be accurately identified. Technical specifications must be prepared so that a system meeting those specifications will indeed be capable of fulfilling operational requirements. The design must guarantee that the functional requirements of the system are met.

Ease of maintenance, repair, and replacement considerations, as well as convenience of use, should influence the design of the system. The hardware configuration should be convenient to service during scheduled maintenance. Parts likely to require the most frequent repair or replacement should be designed to be the most accessible.

System design can also influence the ease of manufacturing and assembly processes. These two processes have been addressed separately in this section to permit a distinction between parts created specifically for system use and off-the-shelf and/or Government-furnished equipment incorporated into the system. The manufacturing and assembly processes must be successful in achieving the design specifications for the system.

Finally, the effectiveness of an existing system depends on the situation in which it is used, maintained, and supported. The users of the system must be trained to use it properly. Maintenance personnel must also have appropriate training, as well as all necessary tools, sufficient spare parts, and an adequate work area. The logistic support of the system must be defined to maximize the effectiveness of the maintenance personnel.

During developmental testing of the TACELIS system, the areas of responsibility must be met by the vendor, the Developmental Tester, and the Materiel Developer. How well each area of responsibility is met can be determined by an analysis of data describing system operation. Of particular interest are all those occasions on which the system fails to meet operational demands.

The impact of all these areas of responsibility can be measured in terms of two variables -- cost and time. It is not within the scope of this report to deal with concepts of cost-effectiveness. The following discussion, therefore, will develop parameters describing system effectiveness in terms of calendar time that elapses during the existence of the completed system.

2.2 PARAMETERS RELATING TO TIME

The time relationships that may be described for the purpose of defining parameters relating to system effectiveness are presented in MIL-STD-721B, 25 August 1966 (with Change Notice 1, 10 March 1970). Figure 2-1 illustrates these time divisions and shows all that time in which the following conditions prevail:

- Use of the system is not required
- The system is on alert status

<table>
<tr><td colspan="12">Active Time</td></tr>
<tr><td colspan="3">Uptime</td><td colspan="9">Downtime</td></tr>
<tr><td>Alert Time</td><td>Reaction Time</td><td>Mission Time</td><td>Modification Time</td><td colspan="8">Maintenance Time</td></tr>
<tr><td colspan="4"></td><td colspan="2">Preventive Maintenance Time</td><td colspan="6">Corrective Maintenance Time</td></tr>
<tr><td colspan="4"></td><td>Servicing Time</td><td>Inspection Time</td><td>Preparation Time</td><td>Fault-Location Time</td><td>Item Obtainment Time</td><td>Fault-Correction Time</td><td>Adjustment-Calibration Time</td><td>Check Out Time</td></tr>
</table>

Figure 2-1. SYSTEM CALENDAR

SYSTEM CALENDAR

- The system is being brought into operation
- The system is performing its function, or mission, successfully
- The system is down

From Figure 2-1, the following time-related parameters can be defined:

- Mean Time Between Failures (MTBF) $= \dfrac{\text{Uptime}}{\text{Number of Failures}}$
- Mean Time To Repair (MTTR) $= \dfrac{\text{Corrective Maintenance Time}}{\text{Number of Corrective Maintenance Actions}}$
- Mean Time Between Maintenance (MTBM) $= \dfrac{\text{Uptime}}{\text{Number of Preventive and Corrective Maintenance Actions}}$
- Mean Maintenance Time (MMT) $= \dfrac{\text{Maintenance Time}}{\text{Number of Preventive and Corrective Maintenance Actions}}$
- Inherent (or Intrinsic) Availability $= \dfrac{\text{Uptime}}{\text{Uptime + Corrective Maintenance Time}}$
- Achieved Availability $= \dfrac{\text{Uptime}}{\text{Uptime + Maintenance Time}}$
- Operational Availability $= \dfrac{\text{Uptime}}{\text{Uptime + Downtime}}$

(All of these concepts have been presented for the sake of completeness. Sufficient data are not available under this contract to develop all of these parameters for the developmental testing of the TACELIS system.)

These foregoing definitions are composed as closely as possible in accordance with the following publications:

- MIL-STD-721B, "Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors and Safety"
- TM 38-750, "The Army Maintenance Management System (TAMMS)"
- AR 702-3, "Product Assurance: Army Materiel Reliability, Availability, and Maintainability"
- AR 70-10, "Test and Evaluation During Development and Acquisition of Materiel"

However, some areas of ambiguity exist among these publications. In addition, the concepts and definitions presented in these documents do not correspond exactly to the data collection situation for developmental testing of the TACELIS system. Therefore, some differences exist between the standard military definitions and their usage in this report.

One obvious area of difficulty is that during developmental testing both uptime and downtime constitute the total demand time for the system.

The demand time occurs during the regular test day work shift of about 8 hours. Modification time (although it may be considered active time) usually occurs at night, when no demands are being made on the system, and therefore is not considered a part of downtime.

In all deployment situations, delay time, modification time, and, to some extent, preventive maintenance time are deferred wherever possible to that segment of the calendar in which no demands are being made on the system. Since the determination of failure in practice frequently rests on the demand status of the system, the time divisions presented in MIL-STD-721B are not completely representative. By dividing active time into demand and nondemand time, some difficulty might be resolved. Clarification would also result from partitioning *inactive time* into *free time* and *storage time*.

The definitions given in TM 38-750 for *preventive maintenance man-hours* and *active repair maintenance man-hours* correspond closely to the *preventive maintenance time* and *corrective maintenance time* of MIL-STD-721B and have been considered to be equivalent for evaluation of data in this study. However, the definitions for *available time, nonavailable time,* and *possible days* given in TM 38-750 do not correspond to any of the time categories in MIL-STD-721B.

One area that remains unresolved is the meaning of *standby time* as used in the definition of operational availability in AR 702-3. For this report, it has been equated to *alert time* as used in MIL-STD-721B. However, some analysts may prefer to extend the time the system is assumed operable into *inactive time*. In addition, there is no formula reported in the Army publications reviewed for this report dealing with uncompleted repair actions. Corrective repair actions for which complete documentation is not available have been omitted from the MTTR calculations in this report.

2.3 LEVELS OF ANALYSIS

The discussion of time-related parameters applies to any defined system. The same analysis can be applied to the entire TACELIS system, to each of the major assemblies, and to each of the Line Replaceable Units within the system. It is only necessary to ensure that whatever is reported as a failure, maintenance action, uptime and downtime, etc., is appropriate to the level being studied.

During developmental testing of the TACELIS system, data are being recorded for use in computing the time-related parameters at two levels -- the major assembly and the Line Replaceable Unit (LRU). The discussion of incident categories applies to data at the LRU level.

2.4 INCIDENT CATEGORIES

If a unit within a system being tested falls below a previously defined acceptable level of operation, the incident is recorded; subsequent evaluation may place the incident in one of these typical categories:

A. The unit failed to meet the operational requirements appropriate to its location and function within the system.

B. The unit did not meet technical specifications.

C. The unit suffered a failure characteristic of the statistical distribution of failures with time for that generic type.

D. The unit was improperly used (including breakage).

E. The unit was poorly maintained or previously not adequately repaired.

F. The unit was defective.

G. The unit was improperly assembled or installed.

H. The incident was improperly diagnosed as attributable to this unit when, in fact, it was the result of a malfunctioning switch, fuse, power supply, etc., critical to the unit but not part of it.

These incident categories may be studied to assign responsibility. For example, the population of incidents in Category C would definitely be counted as failures in an assessment of how successfully a vendor had met unit mean life specifications; those incidents in Category H would not be considered. Incidents described by D, E, and G might be counted as failures in a vendor assessment if they resulted from markedly poor design. All incident categories are of interest to the field user of the system, who simply wants to know how often he can depend on the system when he needs it.

It can be seen from this discussion that the time-related parameters previously defined can have several values depending on evaluation of the reported incidents. The MTBF value reported to a potential user of the system would be quite different from the value used to determine the merit of a vendor's manufactured unit.

2.5 RELIABILITY, AVAILABILITY, AND REPAIRABILITY

One further step may be taken in developing figures of merit from the time-related parameters. If the number of unscheduled failures is taken to be equal to the number of corrective maintenance actions, then the definition of inherent availability can be restated as follows:

$$\text{Inherent Availability} = \frac{\text{Uptime}}{\text{Uptime} + \text{Corrective Maintenance Time}}$$

Let U = uptime
N = number of failures, which is assumed equal to the number of repairs
C = corrective maintenance time

Then

$$\text{Inherent availability} = \frac{U}{U + C}$$

$$= \frac{U/N}{U/N + C/N}$$

$$= \frac{MTBF}{MTBF + MTTR}$$

In the same way,

$$\text{Achieved availability} = \frac{MTBF}{MTBF + MMT}$$

and

$$\text{Operational Availability} = \frac{MTBF}{MTBF + MMT + MDT}$$

where

MDT = mean delay time (see Figure 2-1)

If the time-related parameters, MTBF and MTTR, are assumed to become constant with time as a system or a population of LRUs matures, then the following mathematical definitions are true:

- Reliability. The probability that a system will perform satisfactorily for at least a given period of time, T, when used under specified conditions. Thus

$$\text{Reliability} = \exp\left\{-T/MTBF\right\}$$

- Repairability. The probability that a failed system will be restored to operable condition in a specified active repair time T. Thus

$$\text{Repairability} = \exp\left\{-T/MTBF\right\}$$

In this study, the definitions specified in Sections 2.2 and 2.5 have been used in the analysis of TACELIS developmental test data.

CHAPTER THREE

ANALYSIS OF THE LINE REPLACEABLE UNITS

This chapter presents the analysis of the data describing the Line Replaceable Units; a computational method for improving the analysis is also suggested.

3.1 REQUIRED DATA

The following information should be available to calculate the time-related parameters at the unit level for the TACELIS system:

- A complete listing of the LRU types that constitute the system
- An accurate statement of the number of individual units of each type being used at any time in each of the major assemblies of the system
- A history of the times for which each major assembly was "turned on" or receiving power
- A history of all recorded incidents involving units in the TACELIS system, including preventive and corrective maintenance
- The maintenance time associated with each incident

3.2 ASSUMPTIONS

Certain assumptions have been made to determine the use of these data:

- Malfunction of a unit can occur at any time during which the assembly containing that unit is receiving power, i.e., unit malfunction is defined not only for the duration of operational demand but for all the time the unit is powered (uptime).
- All units that failed during the night (before 0800 hours on the next test day) have been recorded as failing exactly at the beginning of the next test day. All units that failed during a weekend have been recorded as failed at 0800 hours on Monday morning. (This failure-reporting procedure results in an optimistic estimated value of MTBF.)

- After some time has elapsed in the testing of a population of a given unit type, repairs and replacements will affect the character of the population, so that the failure rate and the repair rate for the unit type become constant with time. Constant rates have been assumed in this analysis.

3.3 CALCULATION OF TIME-RELATED PARAMETERS

The statistic MTBF for a given unit type of the TACELIS system can be calculated from the developmental test data as follows:

- Let the major assemblies be designated as CPC, RMS1, RMS2, RSSD, RSSE, RSSF, and RSSG.
- Let $N_{D,CPC}$ be the number of units of a given type functioning in the CPC at the beginning of calendar day D. Let $N_{D,RMS1}$; $N_{D,RMS2}$; $N_{D,RSSD}$; $N_{D,RSSE}$; $N_{D,RSSF}$; and $N_{D,RSSG}$ represent similar figures for the other major assemblies.
- Let $T_{D,CPC}$; $T_{D,RMS1}$; $T_{D,RMS2}$; etc., represent the hours for which power was applied to each of the major assemblies on calendar day D.

Then if no unit failures occurred, the successful unit-hours achieved by the given unit type during calendar day D would be given by

$$(N_{D,CPC} \times T_{D,CPC}) + (N_{D,RMS1} \times T_{D,RMS1}) + \cdot\ \cdot\ \cdot + (N_{D,RSSG} \times T_{D,RSSG})$$

If $R_{D,i}$ is the remedy time for the i^{th} incident involving this unit type on day D, where remedy involves either replacement or on-site repair, then the sum of the remedy times for the day

$$\sum_i R_{D,i}$$

must be subtracted from the expression for "successful unit hours if no failures occurred" to compute actual successful unit hours.

If the remedy time for an incident extends beyond one calendar day, the number of functioning units, N_D, in the affected assembly must be reduced accordingly for subsequent days until the unit is restored. Similarly, if a unit that was not operating at the beginning of a day is restored during that calendar day, the number of successful unit-hours for that day must be incremented to reflect the restoration.

For any specified calendar period, the MTBF for the unit type can be found by computing the successful unit-hours accumulated for all the major assemblies throughout all the calendar days for that period and dividing by the failures recorded for that unit type during the same period.

The statistic MTTR for a given unit type is calculated by dividing the sum of all completed repair times by the number of all completed repairs (Section 2.2, Chapter Two).

Since the failure rate and repair rate for a population of one unit type are assumed to be constant with time, the times between failure and times to repair for that population are taken to be exponentially distributed. Therefore, the chi-square formula is used for the confidence-interval computations for the MTBF and MTTR estimates. The values presented in this report are given with symmetrical, 80 percent confidence limits.

Chapter Nine lists the LRUs of the TACELIS system identified in this study by ARINC Research in cooperation with the Test Engineer for the Developmental Tester. For each identified unit, it presents estimates of MTBF, MTTR, and unit reliability (for a time period of 24 hours), together with 80 percent symmetric confidence limits. These data are reported to demonstrate the methodology for the RAM assessment of the TACELIS system, but they must be used only to indicate general trends. These data were extracted from Equipment Performance Reports, which represent an edited version of the original data record (the Maintenance Request), omitting much useful information. Failures were categorized by calendar days only; thus the time of day at which failure occurred could not be accounted for. An accurate record of the actual numbers of each type of unit deployed in the various major assemblies could not be obtained from the Developmental Tester. As a result, the computations in several cases may not accurately reflect the test situation. Records describing unit modifications during the course of developmental testing are likewise not available for this study. Therefore, caution must be exercised in drawing inferences from the values presented in this report.

3.4 ELIMINATION OF BIAS

In conducting the RAM analysis for developmental testing of the TACELIS system, the data-collection personnel for the Developmental Tester will have the actual time-of-day failure information for all observed failures, which was not available for the analysis described in this study. Therefore, the statistic MTBF can be computed as described in Section 3.3. However, under the current data-handling methods, units that fail unobserved (i.e., during the night and on weekends) are reported as failing at 0800 hours on the first subsequent test day (demand time). This practice will systematically introduce a bias in the calculated estimate of MTBF from developmental test data. A method for improving this estimate is presented here.

The exact time at which the unit failure occurs between the end of one test shift and the beginning of another is not observed. Therefore, for each case the operating hours between the end of the previous test shift and the time of unit failure must be estimated. The procedure recommended is to increment the operating hours credited to the failing unit prior to failure by the *expected time to failure* for the unit, given that failure did indeed occur between the test shifts.

Let the variable T represent Time To Failure for a population of a given unit type.

The density function, $g(T)$, of Times To Failure for the unit type is exponential, i.e.,

$$g(T) = \lambda e^{-\lambda T}$$

where

$$\lambda = \frac{1}{MTBF}$$

If the constant T_s is defined as the elapsed time between test shifts, then the Time To Between-Shift Failure, θ, is a random variable such that

$$0 \leq \theta \leq T_s$$

The density function of θ is given by the truncated exponential

$$F(\theta) = \frac{\lambda e^{-\lambda\theta}}{1-e^{-\lambda T_s}}$$

The density function of θ will now be explained with reference to Figure 3-1.

The area under the curve $g(T) = \lambda e^{-\lambda T}$ represents the population of failures for the given unit type.

The shaded area represents the population of between-shift failures and is expressed by

$$\int_0^{T_s} \lambda e^{-\lambda T}\, dT$$

To derive a density function $F(\theta)$ for the population of between-shift failures, we use the fact that the shaded area must be equal to unity if it represents a total population; i.e., the original density function for Time To Failure must be normalized to describe Time To Between-Shift Failure. Then

$$\begin{aligned}\int_0^{T_s} \lambda e^{-\lambda T}\, dT &= \left[-e^{-\lambda T}\right]_0^{T_s} \\ &= -e^{-\lambda T_s} - \left(-e^{-\lambda \cdot 0}\right) \\ &= -e^{-\lambda T_s} + 1 \\ &= 1 - e^{-\lambda T_s}\end{aligned}$$

represents the shaded area.

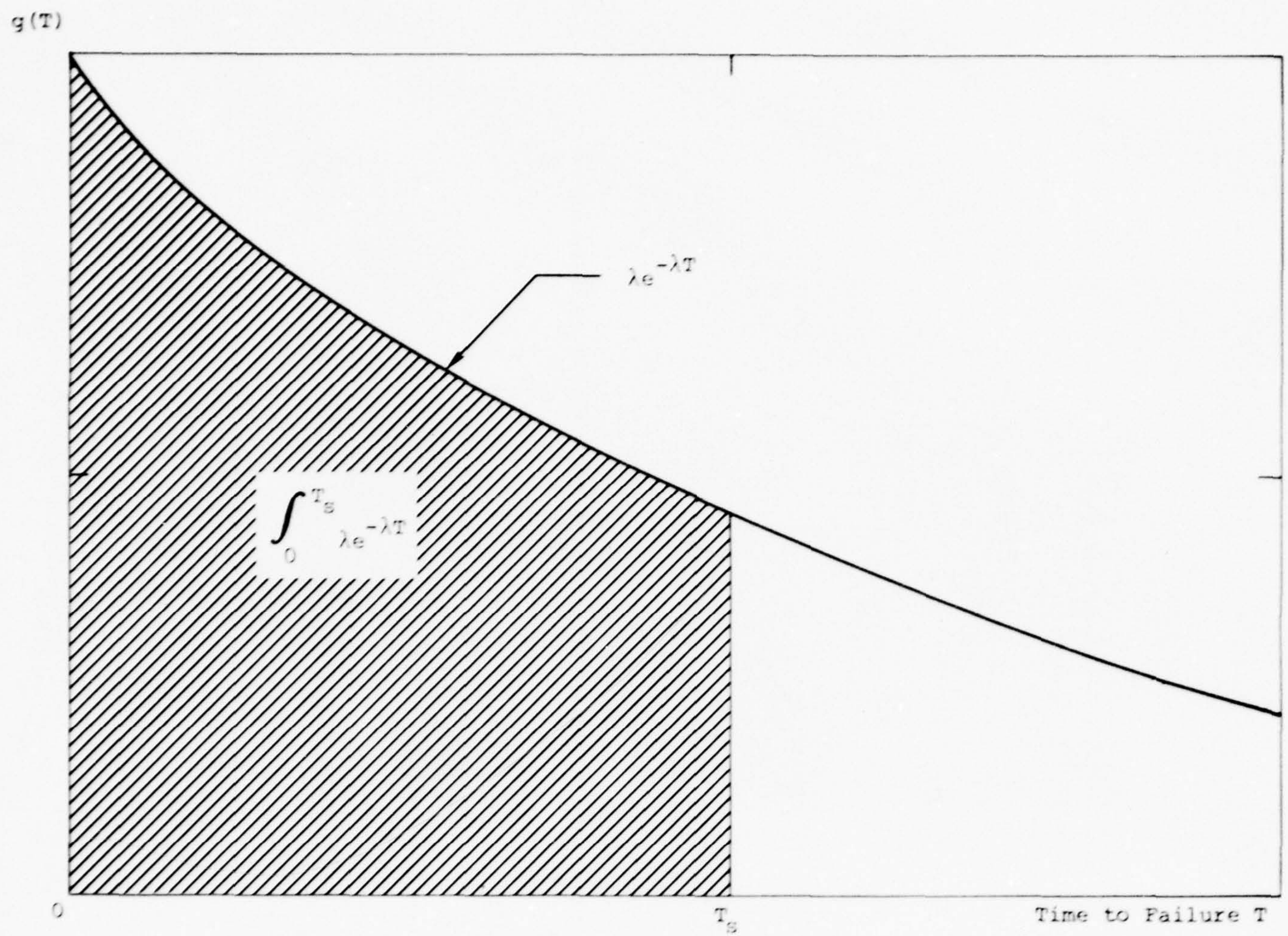


Figure 3-1. TRUNCATED EXPONENTIAL DISTRUBUTION OF TIMES TO BETWEEN-SHIFT FAILURES

The fraction of between-shift failures occurring in the interval $d\theta$ is given by

$$\frac{\lambda e^{-\lambda\theta}\, d\theta}{1 - e^{-\lambda T_s}}$$

Then

$$\int_0^{T_s} \frac{\lambda e^{-\lambda\theta}\, d\theta}{1 - e^{-\lambda T_s}} = \frac{\lambda}{1 - e^{-\lambda T_s}} \left[- \frac{e^{-\lambda\theta}}{\lambda}\right]_0^{T_s}$$

$$= \frac{1}{1 - e^{-\lambda T_s}} \left[-e^{-\lambda T_s} + e^{-\lambda \cdot 0}\right]$$

$$= \frac{1 - e^{-\lambda T_s}}{1 - e^{-\lambda T_s}} = 1$$

Therefore the function

$$F(\theta) = \frac{\lambda e^{-\lambda\theta}}{1 - e^{-\lambda T_s}}$$

has the desired property.

The expected value of Time To Between-Shift Failure is

$$E(\theta) = \int_0^{T_s} \theta \cdot F(\theta)\, d\theta$$

This expected value can be computed as follows:

$$\int_0^{T_s} \frac{\theta \cdot \lambda e^{-\lambda\theta}\, d\theta}{1 - e^{-\lambda T_s}} = \frac{\lambda}{1 - e^{-\lambda T_s}} \int_0^{T_s} \theta e^{-\lambda\theta}\, d\theta$$

$$= \frac{\lambda}{1 - e^{-\lambda T_s}} \left[\frac{e^{-\lambda\theta}}{-\lambda} \left(\theta - \frac{1}{-\lambda}\right)\right]_0^{T_s}$$

$$= \frac{1}{1 - e^{-\lambda T_s}} \left[e^{-\lambda\theta} \left(\theta + \frac{1}{\lambda}\right)\right]_{T_s}^{0}$$

$$= \frac{1}{1 - e^{-\lambda T_s}} \left[\frac{1}{\lambda} - e^{-\lambda T_s} \left(T_s + \frac{1}{\lambda} \right) \right]$$

$$= \frac{1}{1 - e^{-\lambda T_s}} \left[\frac{1 - e^{-\lambda T_s}}{\lambda} - T_s \, e^{-\lambda T_s} \right]$$

$$= \frac{1}{\lambda} - \frac{T_s \, e^{-\lambda T_s}}{1 - e^{-\lambda T_s}}$$

This result shows that the expected value of Time To Between-Shift Failure can be expressed in terms of the statistic MTBF for the generic LRU type as

$$E(\Theta) = \text{MTBF} - \left[\frac{T_s}{e^{\lambda T_s} - 1} \right]$$

since $\frac{1}{\lambda}$ = MTBF.

The operating hours credited to units failing unobserved can be incremented by the MTBF value calculated for that unit type from test data collected up to that time reduced by the correction term:

$$\frac{T_s}{e^{\lambda T_s} - 1}$$

Although the failure data provided to ARINC Research did not include enough information to permit use of this correction factor in computing MTBF for the TACELIS Line Replaceable Units, it is recommended that the Developmental Tester use this correction term. The data bank available to the Developmental Tester for RAM analysis of the TACELIS system contains enough information to apply this procedure.

CHAPTER FOUR

ANALYSIS OF THE MAJOR ASSEMBLIES

This chapter presents the reliability block diagrams for the major assemblies of the TACELIS system, together with the corresponding mathematical models.

4.1 RELIABILITY BLOCK DIAGRAMS

Chapter Three presented the calculation of reliability values for all the Line Replaceable Units in the TACELIS system. The methodology for using these LRU reliability values to compute the hardware reliability of the major assemblies is explained in this chapter. Three major assemblies were studied:

- The Control and Processing Center (CPC)
- The Remote Master Station (RMS)
- The Remote Slave Station (RSS)

Each TACELIS major assembly performs a variety of tasks relating to the information collection, transfer, processing, and recording capabilities required to accomplish the total mission of the system. Theoretically, at any given time the level of operation of a TACELIS major assembly could vary from "full up" (with every LRU functioning to specifications), through all possible combinations of degraded states of these capabilities, to the failure of all the LRUs. A block diagram configured for the determination of assembly reliability is entirely dependent on the definition of assembly failure chosen from this spectrum of possibilities. A minimum level of acceptable assembly operation must be stated for each capability. All states exceeding this level are defined to be system success. If any capability degrades below its defined minimum level, the assembly is considered to fail.

The concept of redundancy is fundamental to the discussion of assembly failure. To develop this concept, redundancy is defined as the existence within the assembly of more than one means, or path, for accomplishing a given task. The functional diagrams of the TACELIS major assemblies -- CPC, RMS, and RSS -- have been examined in detail by ARINC Research to

determine all possible paths for successful assembly operation. Wherever more than one path exists for the accomplishment of a specific task, the reliability diagram is drawn to show parallel paths. Those elements which are essential to assembly operation and whose failure would cause assembly failure are shown in series with the other system elements. The reliability block diagrams for the CPC, RMS, and RSS are shown in Figures 4-1, 4-2, and 4-3, respectively.

The following assumptions have been made in determining the level of system operation below which failure is considered to occur:

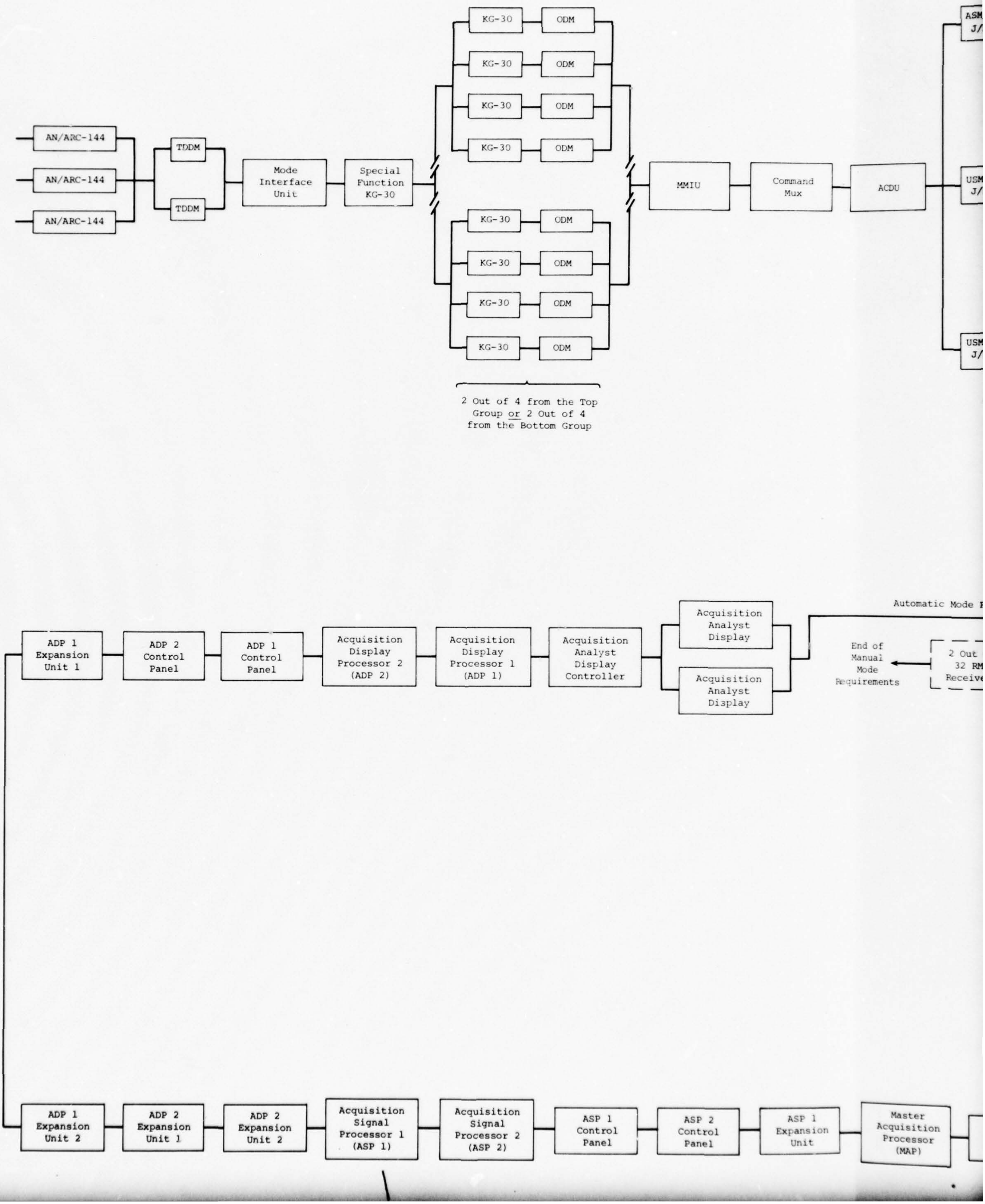
- The Maintenance Operator Position (MOP) is essential for system initialization and for any necessary reconfiguration. While it is true that the system could function for a short time without this position once it has been initialized, the next critical incident requiring reconfiguration would represent certain failure. With the MOP in operation, however, several kinds of critical incidents can be successfully resolved. Therefore, the MOP must remain operative for success.
- In defining system success, Line of Bearing (LOB) information is required. Therefore, at least one Location Analyst Position must remain operative.
- Multi-channel information is not considered essential.
- Only one RMS branch is required to remain in operation.
- The panoramic (pan) displays are not considered necessary; therefore, the pan display and pan preprocessor hardware is not considered essential.
- The fault monitor function at the MOP is not considered essential.
- System success is said to occur if only one of the four frequency bands is available.

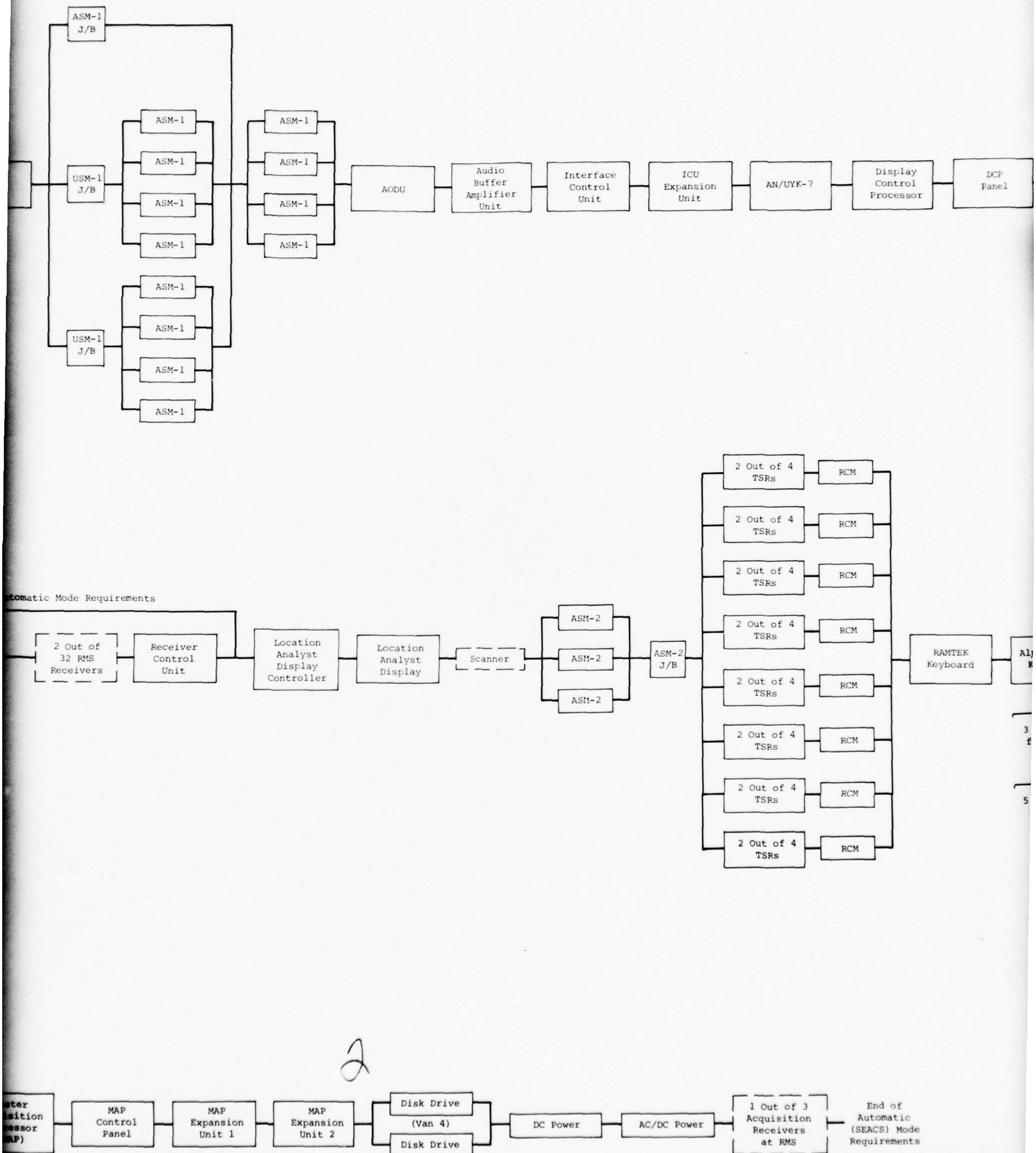
4.2 THREE-STATE MODELS

Each of the three major assemblies has been diagrammed in such a way that three states, or levels, of operation can be defined for the assembly. This has been done (1) to show how the state concept is implemented in the reliability block diagrams and (2) to provide examples for the discussion of a three-state model in Chapter Six.

For the Control and Processing Center three states are defined as follows:

- State 1. All units essential to successful system function (as defined in Section 4.1) are operating.
- State 2. A manual mode of operation is still possible. The automatic signal-collection capability of the TACELIS system has been


AN/ARC-144
AN/ARC-144
AN/ARC-144
TDDM
TDDM
Mode Interface Unit
Special Function KG-30
KG-30
ODM
MMIU
Command Mux
ACDU
2 Out of 4 from the Top Group or 2 Out of 4 from the Bottom Group
Automatic Mode
ADP 1 Expansion Unit 1
ADP 2 Control Panel
ADP 1 Control Panel
Acquisition Display Processor 2 (ADP 2)
Acquisition Display Processor 1 (ADP 1)
Acquisition Analyst Display Controller
Acquisition Analyst Display
Acquisition Analyst Display
End of Manual Mode Requirements
ADP 1 Expansion Unit 2
ADP 2 Expansion Unit 1
ADP 2 Expansion Unit 2
Acquisition Signal Processor 1 (ASP 1)
Acquisition Signal Processor 2 (ASP 2)
ASP 1 Control Panel
ASP 2 Control Panel
ASP 1 Expansion Unit
Master Acquisition Processor (MAP)



ASM-1 J/B
USM-1 J/B
USM-1 J/B
ASM-1
ASM-1
ASM-1
ASM-1
ASM-1
ASM-1
ASM-1
ASM-1
ASM-1
ASM-1
ASM-1
ASM-1
AODU
Audio Buffer Amplifier Unit
Interface Control Unit
ICU Expansion Unit
AN/UYK-7
Display Control Processor
DCP Panel
tomatic Mode Requirements
2 Out of 32 RMS Receivers
Receiver Control Unit
Location Analyst Display Controller
Location Analyst Display
Scanner
ASM-2
ASM-2
ASM-2
ASM-2 J/B
2 Out of 4 TSRs
RCM
2 Out of 4 TSRs
RCM
2 Out of 4 TSRs
RCM
2 Out of 4 TSRs
RCM
2 Out of 4 TSRs
RCM
2 Out of 4 TSRs
RCM
2 Out of 4 TSRs
RCM
2 Out of 4 TSRs
RCM
RAMTEK Keyboard
MAP Control Panel
MAP Expansion Unit 1
MAP Expansion Unit 2
Disk Drive
(Van 4)
Disk Drive
DC Power
AC/DC Power
1 Out of 3 Acquisition Receivers at RMS
End of Automatic (SEACS) Mode Requirements

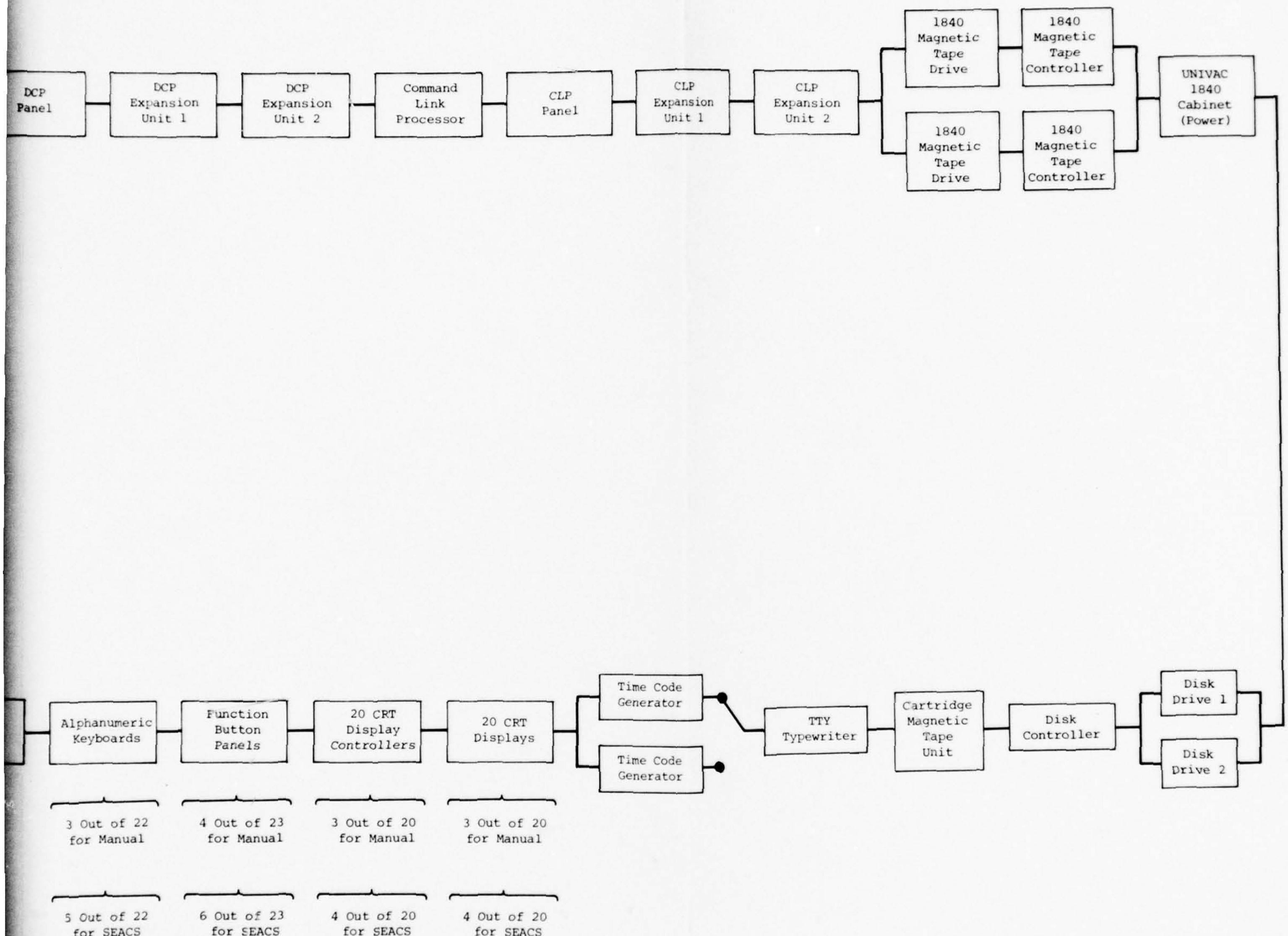


Figure 4-1. RELIABILITY DIAGRAM FOR THE CONTROL AND PROCESSING CENTER

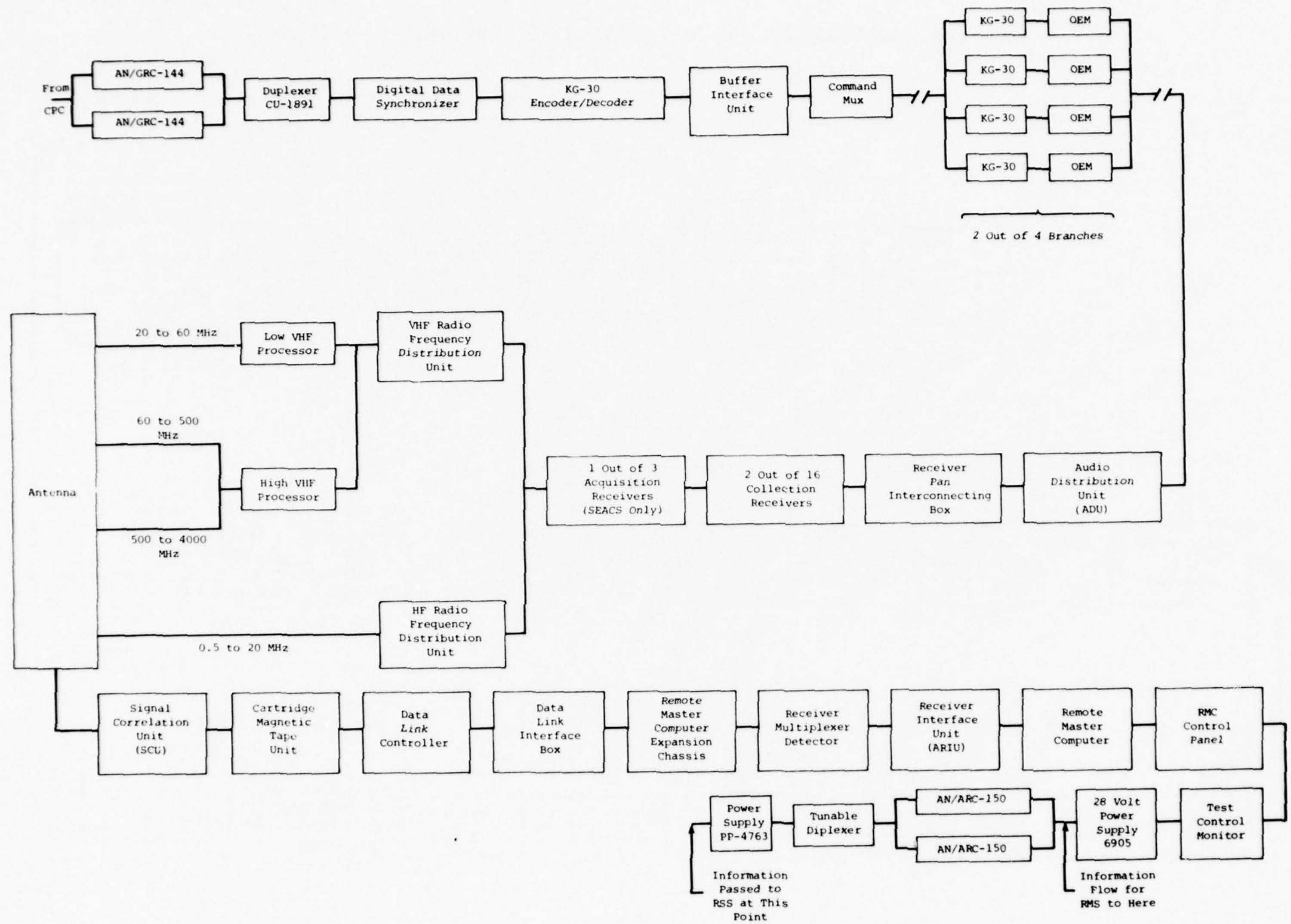


Figure 4-2. RELIABILITY DIAGRAM FOR THE REMOTE MASTER STATION

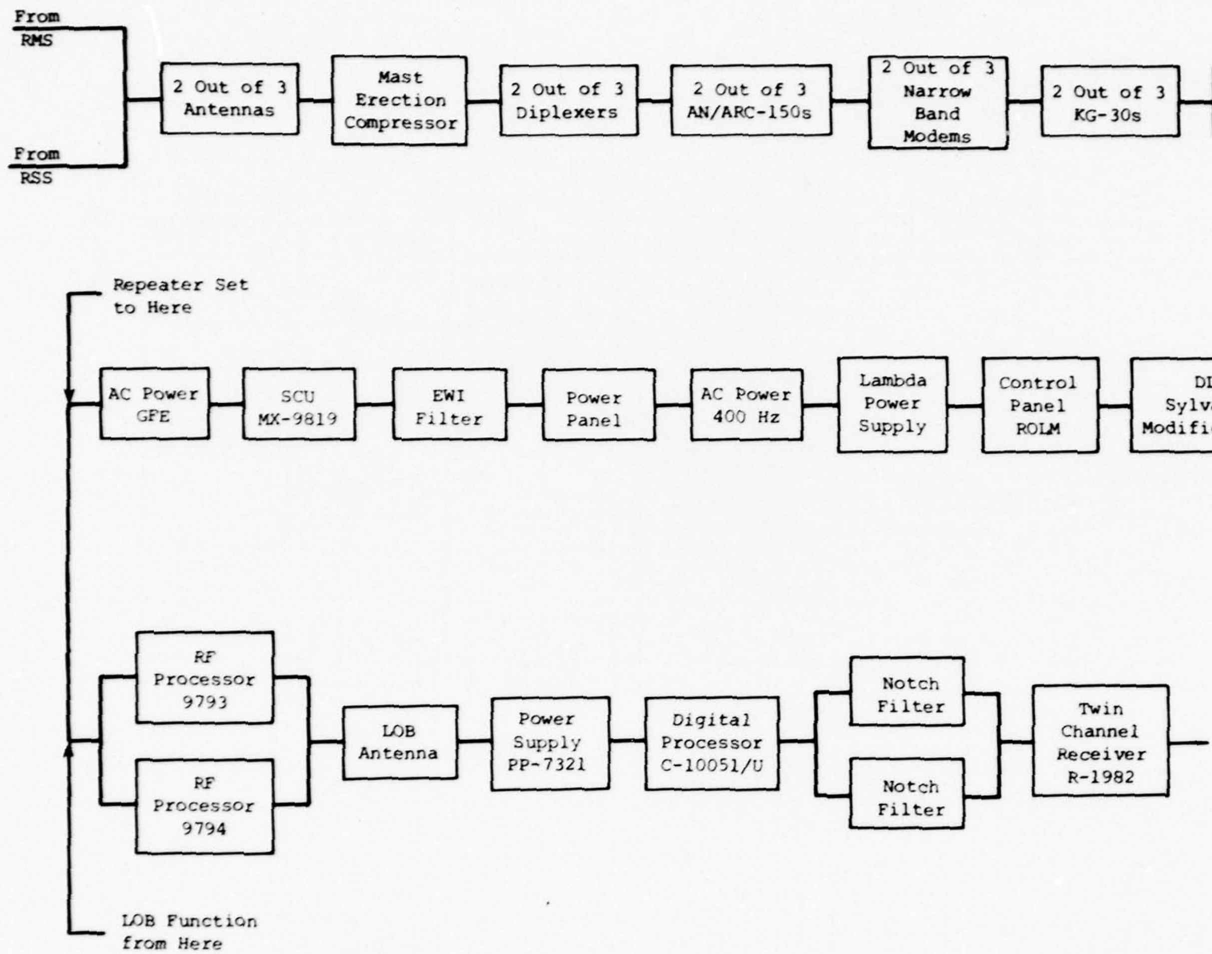


Figure 4-3. RELIABILITY DIAGRAM FOR THE REMOTE SLAVE STATION

lost, and bandwidth coverage is obtained by tuning the system receivers manually.

- State 3. Not enough equipment is operable to permit collection and analysis of signals.

The three states defined for the RMS show the RMS (1) functioning fully in communication with the associated RSSs, (2) functioning as an RMS but unable to communicate with the RSSs, and (3) failed.

Up to four Remote Slave Stations may be "daisy-chained" together so that each communicates only with the two immediately adjacent in the chain. All have the function of collecting LOB information for the system. Therefore, even if an RSS loses its LOB capability, it is left in the chain to relay information between its two neighbors. The three states chosen to define RSS capability reflect this fact:

- State 1. The RSS is capable of collecting LOB data, in addition to relaying communications between its two adjacent neighbors in the "daisy-chain".
- State 2. The RSS has lost its LOB data-collection ability but is left in place to function as a repeater set.
- State 3. The RSS cannot relay information.

4.3 MATHEMATICAL MODELS

In developing a mathematical representation for the reliability of each of the major assemblies from the block diagrams, the following notation will be used:

P_i = the probability of success, or reliability, of the i^{th} Line Replaceable Unit

Q_i = the probability of failure, or unreliability, of the i^{th} Line Replaceable Unit

For all units $(P_i + Q_i) = 1$

The reliability of n units in series is $P_1 \cdot P_2 \ldots P_n$

The reliability of k units in parallel is $1 - Q_1 \cdot Q_2 \ldots Q_k$

These concepts will be expanded to develop the mathematical descriptions of the CPC, RMS, and RSS.

It is emphasized that the expressions for assembly reliability developed in this chapter relate to hardware reliability only. The major assemblies of the TACELIS system are also vulnerable to incidents of software failure, which have not been included by the customer within the scope of this study. Assembly reliability values for a 24-hour mission time are given in Chapter Nine.

4.4 RELIABILITY OF THE CPC

The formula for the reliability of the Control and Processing Center is given here with reference to Figure 4-1 (it is emphasized that this description of the assembly considers hardware only):

$$R_{CPC} = \left(1 - Q^3_{ARC-144}\right)\left(1 - Q^2_{TDDM}\right)\left(P_{MIU}\right)\left(P_{KG-30}\right)\left(P_{MMIU}\right)\left(P_{COM\ MUX}\right)\left(P_{ACDU}\right)$$

$$\times\left\{1 - \left\{1 - \left[6\left(P_{KG-30} \cdot P_{ODM}\right)^2 - 8\left(P_{KG-30} \cdot P_{ODM}\right)^3 + 3\left(P_{KG-30} \cdot P_{ODM}\right)^4\right]\right\}^2\right\}$$

$$\times \left(P_{AODU}\right)\left(P_{ABAU}\right)\left(P_{ICU}\right)\left(P_{ICU-EXP}\right)\left(P_{AN/UYK7}\right)\left(P_{DCP}\right)\left(P_{DCP\ PANEL}\right)$$

$$\times \left\{1 - Q_{ASM-1\ J/B}\left[1 - P_{ASM-1\ J/B}\left(1 - Q^4_{ASM-1}\right)\right]^2\right\}\left\{1 - Q^4_{ASM-1}\right\}$$

$$\times \left(P^2_{DCP\ EXP}\right)\left(P_{CLP}\right)\left(P_{CLP\ PANEL}\right)\left(P^2_{CLP\ EXP}\right)\left(P_{UNI\ POWCAB}\right)$$

$$\times \left\{1 - \left[1 - \left(P_{1840\ DRIVE}\right)\left(P_{1840\ CONT}\right)\right]^2\right\}$$

$$\times \left[1 - \left(Q_{DISK\ DRIVE\ 1}\right)\left(Q_{DISK\ DRIVE\ 2}\right)\right]$$

$$\times \left(P_{DISK\ CONT}\right)\left(P_{CMTU}\right)\left(P_{TTY\ TYPE}\right)\left[1 - Q^2_{TCG}\right]$$

$$\times \begin{bmatrix}\text{CRT DISPLAY}\\ \text{TERM}\end{bmatrix} \times \begin{bmatrix}\text{CRT DISPLAY}\\ \text{CONTROLLER TERM}\end{bmatrix} \times \begin{bmatrix}\text{FBP}\\ \text{TERM}\end{bmatrix} \times \begin{bmatrix}\text{KEYBOARD}\\ \text{TERM}\end{bmatrix}$$

$$\times \left\{1 - \left[1 - P_{RCM}\left(6P^2_{TSR} - 8P^3_{TSR} + 3P^4_{TSR}\right)\right]^8\right\}$$

$$\times \left(P_{ASM-2\ J/B}\right)\left(1 - Q^3_{ASM-2}\right)\left(P_{LA\ DISP}\right)\left(P_{LA\ DISP\ CONT}\right)$$

For manual mode only:

$$\times \left(P_{REC\ CONT\ UNIT}\right)$$

For SEACS mode

$$\times\left(1 - Q^2_{AA\ DISP}\right)\left(P_{AA\ DISP\ CONT}\right)\left(P_{ADP1}\right)\left(P_{ADP2}\right)\left(P_{ADP1\ PANEL}\right)\left(P_{ADP2\ PANEL}\right)$$

$$\times\left(P_{ADP1\ EXP\ 1}\right)\left(P_{ADP1\ EXP\ 2}\right)\left(P_{ADP2\ EXP\ 1}\right)\left(P_{ADP2\ EXP\ 2}\right)\left(P_{ASP1}\right)\left(P_{ASP2}\right)$$

$$\times\left(P_{ASP1\ PANEL}\right)\left(P_{ASP2\ PANEL}\right)\left(P_{ASP1\ EXP}\right)\left(P_{MAP}\right)\left(P_{MAP\ PANEL}\right)\left(P_{MAP\ EXP\ 1}\right)$$

$$\times\left(P_{MAP\ EXP\ 2}\right)\left(1 - Q^2_{DISK\ DRIVE}\right)\left(P_{DC\ POWER}\right)\left(P_{AC/DC}\right)$$

where the operator position terms are computed as follows:

- CRT DISPLAYS and CRT DISPLAY CONTROLLERS

Manual Mode

$$\sum_{x=3}^{20} \frac{20!}{x!\ (20-x)!} P^x Q^{20-x}$$

SEACS Mode

$$\sum_{x=4}^{20} \frac{20!}{x!\ (20-x)!} P^x Q^{20-x}$$

- FUNCTION BUTTON PANELS and ALPHANUMERIC KEYBOARDS

Manual Mode

$$\sum_{x=4}^{23} \frac{23!}{x!\ (23-x)!} P^x Q^{23-x}$$

SEACS Mode

$$\sum_{x=6}^{23} \frac{23!}{x!\ (23-x)!} P^x Q^{23-x}$$

4.5 RELIABILITY OF THE RMS

The formula for the hardware reliability of a Remote Master Station is developed with reference to Figure 4-2:

$$\begin{aligned} R_{RMS} = & \left(1 - Q^2_{144}\right)\left(P_{1891}\right)\left(P_{DD\ SYNC}\right)\left(P_{KG-30}\right)\left(P_{BUFF\ IU}\right)\left(P_{COM\ MUX}\right) \\ & \times \left[6\left(P_{KG-30} \cdot P_{OEM}\right)^2 - 8\left(P_{KG-30} \cdot P_{OEM}\right)^3 + 3\left(P_{KG-30} \cdot P_{OEM}\right)^4\right] \\ & \times \left(P_{ADU}\right)\left(P_{RPI\ BOX}\right)\left[\sum_{x=2}^{16} \frac{16!}{x!\ (16-x)!} P^x_{COL\ REC}\left(1-P_{COL\ REC}\right)^{16-x}\right] \\ & \times \left(1 - Q^3_{ACQ\ REC}\right)\left\{1 - \left[1 - P_{VHF\ DU}\left(1 - Q_{LO\ VHF} \cdot Q_{HI\ VHF}\right)\right] Q_{HF\ DU}\right\} \\ & \times \left(P_{SCU}\right)\left(P_{CMTU}\right)\left(P_{DLC}\right)\left(P_{DL\ I-BOX}\right)\left(P_{RMC\ EXP}\right)\left(P_{RMD}\right) \\ & \times \left(P_{ARIU}\right)\left(P_{RMC}\right)\left(P_{RMC\ PANEL}\right) \\ & \times \left(P_{MONITOR}\right)\left(P_{6905}\right) \end{aligned}$$

For Remote Slave Station control, the following terms must be added to the product:

$$\left(1 - Q^2_{ARC-150}\right)\left(P_{TUN\ DIP}\right)\left(P_{4763}\right)$$

4.6 RELIABILITY OF THE RSS

The equation for the reliability of the Remote Slave Station is developed with reference to Figure 4-3:

$$R_{RSS} = \left(3P^2_{ANTENNA} - 2P^3_{ANTENNA}\right)\left(P_{MAST\ ERECT}\right)$$

$$\times\left(3P^2_{DIPLEX} - 2P^3_{DIPLEX}\right)\left(3P^2_{ARC-150} - 2P^3_{ARC-150}\right)$$

$$\times\left(3P^2_{NB\ MOD} - 2P^3_{NB\ MOD}\right)\left(3P^2_{KG-30} - 2P^3_{KG-30}\right)$$

$$\times\left(P_{1602}\right)\left(P_{CMTU}\right)\left(P_{9771}\right)\left(P_{DLC}\right)\left(P_{ROLM\ PANEL}\right)\left(P_{\lambda\ POWER}\right)$$

$$\times\left(P_{400\ HZ}\right)\left(P_{POWER\ PANEL}\right)\left(P_{EWI\ FILT}\right)\left(P_{SCU}\right)\left(P_{AC}\right)$$

For the LOB data-collection function, these additional factors must be included in the product:

$$\times\left[1 - \left(Q_{9793}\right)\left(Q_{9794}\right)\right]\left(P_{LOB\ ANT}\right)\left(P_{7321}\right)\left(P_{10051}\right)$$

$$\times\left(1 - Q^2_{NOTCH\ FILTER}\right)\left(P_{1982}\right)$$

4.7 SENSITIVITY ANALYSIS

It is obvious that the process of calculating R_{CPC}, R_{RMS}, and R_{RSS} from the given formulas is a tedious one. To recalculate each time it is desirable to assess the effect of modifications on assembly reliability would be unnecessarily time-consuming. However, conveniently chosen segments of the block diagram may be examined independently.

For any assembly consisting of three units A, B, and C connected in series, the reliability of the assembly R_{ABC} is given by

$$R_{ABC} = R_A \times R_B \times R_C$$

Similarly, the reliability of any TACELIS assembly can be considered to be the product of the reliabilities of several segments constituting the assembly, *if the segments are so chosen that they are all in series*. This approach will be developed in Chapter Seven to show the sensitivity of assembly reliabilities to modification. This approach permits the effect of modification on one term of the product to be observed. The effect on the product, or total assembly reliability, is directly proportional.

CHAPTER FIVE

ANALYSIS OF THE TACELIS SYSTEM

This chapter describes the reliability of the total TACELIS system as a function of mission time.

5.1 THE DATA BASE

In Chapter Four the reliability of the major assemblies was modeled algebraically from the study of reliability block diagrams describing the LRUs, or hardware elements, essential to assembly operation. This analysis was performed to demonstrate the use of block diagrams, but it does not give a complete description of assembly reliability since it does not account for software failures. Software failure incident reports have not been included by the customer in the scope of this study.

The chronological run logs from the TACELIS developmental testing for the calendar period covered by the Equipment Performance Reports delivered to ARINC Research have been used to develop assembly reliability figures. A sample run log sheet is shown in Figure 5-1. These run logs show uptime and downtime for each of the major assemblies throughout the first year of developmental testing. Although software failure incident reports were not a part of this study, the definitions for assembly success that determined whether an assembly was considered to be "up" or "down" for the chronological run logs included software considerations; in fact, almost all of the assembly failures (or transitions to the "down" state) were software-induced. Therefore, although these values cannot be compared with the models developed in Chapter Four, they have been used for the calculation of total system reliability since they are more representative of the real situation (i.e., they include software-related assembly state transitions).

The statistics MTBF and MTTR have been developed for the CPC, RMS, and RSS in a manner analogous to that described in Chapter Three for the LRUs. The total assembly hours for each assembly type have been divided by the number of up-to-down transitions for that type to produce MTBF values. The total downtime for each assembly type has been divided by the number of down-to-up transitions for that type to compute MTTR figures. These results are presented in Table 5-1.

SYSTEM CONFIGURATION STATUS

Date: 13 Feb 78

UP/ TIME	DOWN/ TIME	[illegible]	Pms #1	Pss F	Pms #2	Pss E	Pss G	[illegible]	REMARKS *2
0630			36 X	X	X	X	O	O	Sent personal to Pms #2 to load computers sites not ready then
0705				X	X	X	O	O	Pms #2 load
0802				X	X	X	O	O	Personal at sites starting to load computer at that time
0812				X	115 X	X	O	O	Pms #2 loaded but no [illegible]
	0825			X		X	O	O	Can not load Pss E
	0845			X		X	O	O	Still can Not load Pss E
	0915			X	15 X	X	O	O	Pms #2 will do loop link with Pss
0930				X		X	O	O	Pms #2 back in service will try to
	0935			467 X		X	O	O	Pss E still won't load
	1015			X	X	X	O	O	Pms #2 blown fuse
1016				X		X	O	O	Pms #2 replaced fuse
	1034		199 X	X		X	O	O	Pms #2 will do loop link with Pss.
	1310		X	X		X	O	O	Can not bring up Pms #2, Pss E
1353				X		X			Pms #2 back in service
1402						X	O	O	Pss E in service
	1430				61 X	X	O	O	took Pms #2 out of service and [illegible]
	1527	3 X	3 X	3	X	X	O	O	Errored 201
1530					X	X	O	O	System up
	1600	X	X	X	X	X	O	O	Err mod 176
	1601								End of test

NOTE: An "X" in column implies malfunctioning or out of service because of some other malfunction.

An "O" in column implies NOT REQUIRED FOR TEST.

Time Down	0.04	3:59	7:46	3:12	9:31	0:00	0:00
Total Time	9:31	9:31	9:31	9:31	9:31	0:00	0:00

Figure 5-1. SAMPLE OF CHRONOLOGICAL RUN LOG

Table 5-1. MTBF AND MTTR FOR THE MAJOR ASSEMBLIES		
Assembly	MTBF (Hours)	MTTR (Hours)
CPC	3.10	.37
RMS	1.80	.61
RSS	1.60	1.00

Reliability values developed for the major assemblies from these statistics are given in Table 5-2.

Table 5-2. RELIABILITY VALUES FOR THE MAJOR ASSEMBLIES			
Assembly	Mission Time		
	1 Hour	2 Hours	3 Hours
CPC	.72	.52	.38
RMS	.57	.33	.19
RSS	.53	.29	.15

The major assemblies of the TACELIS intelligence-gathering system can be combined in several ways. The total number of possible configurations is determined by the number of "building blocks" available to the field user of the system:

- 1 Control and Processing Center
- 2 Remote Master Stations
- 8 Remote Slave Stations

The allowable assembly interfaces are governed by the following rules:

- The Control and Processing Center can be linked to 0, 1, or 2 Remote Master Stations, as shown in Figure 5-2.
- Each of the eight Remote Slave Stations is equipped with three data links, two of which are required for normal operation. The third data link is used only when this assembly type is designated as a Master Remote Slave Station (MRSS) and assigned the role of interfacing between other Remote Slave Stations (RSSs) and the Remote Master Station (RMS). Communication between an RMS and any PSS must always be made through an MRSS.

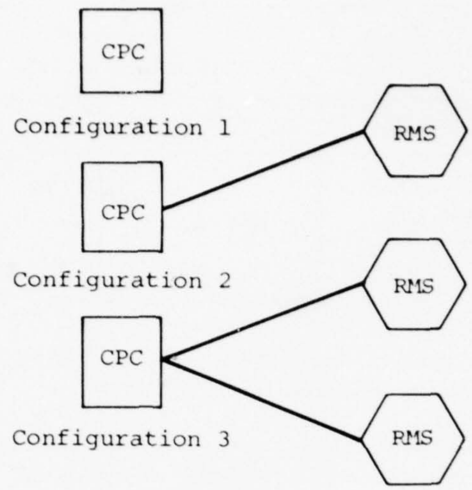


Figure 5-2. CPC-RMS LINKS

- Up to eight Remote Slave Stations (one a designated Master Remote Slave Station) can be slaved to one Remote Master Station.
- Each Remote Master Station can relay signals from only one Master Remote Slave Station to the Control and Processing Center.
- Each Master Remote Slave Station can have no more than two links to Remote Slave Stations.
- Remote Slave Stations can be "daisy-chained".

5.2 OPTIONS FOR THE CPC-RMS LINK

All possible options for the CPC-RMS link are illustrated in Figure 5-2. The CPC can stand alone, be linked with one RMS, or be linked with two RMSs. Selected reliability values for Configuration 2 are as follows:

Mission Hours	Reliability
1	.41
2	.17
3	.07

The probability of retaining at least one CPC-RMS link in Configuration 3 is as follows:

Mission Hours	Reliability
1	.59
2	.29
3	.13

5.3 RELIABILITY OF THE TOTAL SYSTEM

The estimates of mission reliability for the total system depend on the system configuration. Mission reliabilities are given in Table 5-3 for the various configurations shown in Figure 5-3. The definition of success is that at least one CPC-RMS-RSS path must remain available. In addition, two RSSs must remain functional and in communication with an RMS so that LOB information is obtained on intercepted signals. The effect of RSS redundancy in improving reliability is apparent. The reliability of any desired configuration can be computed by using the methods described in Chapter Four.

Table 5-3. ONE-HOUR MISSION RELIABILITIES FOR THREE TACELIS CONFIGURATIONS

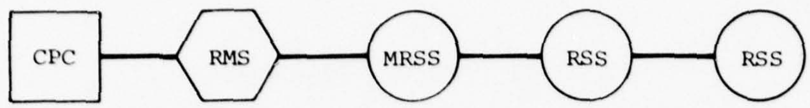
Configuration	Reliability
Series	.115
RMS Redundancy	.212
RSS Redundancy	.299

If difficulties are repeatedly encountered in improving the MTBF values for the Remote Slave Station assembly, significant improvement in system reliability can still be obtained by using configurations in which the Master Remote Slave Station is linked to two Remote Slave Stations. In fact, for full-strength deployment of the TACELIS system, with four RSSs reporting to one RMS, the interfaces

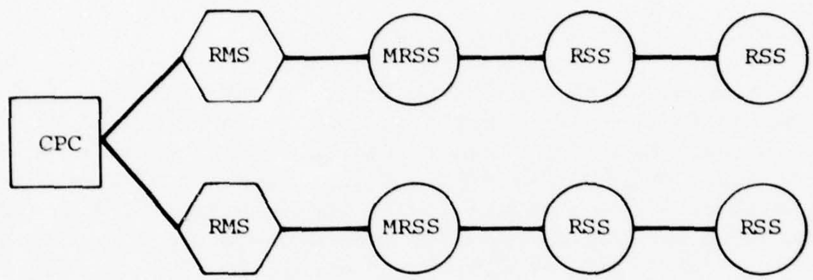
```
                      / RSS —— RSS
CPC — RMS — MRSS <
                      \ RSS
```

are always preferable, from a reliability viewpoint, to

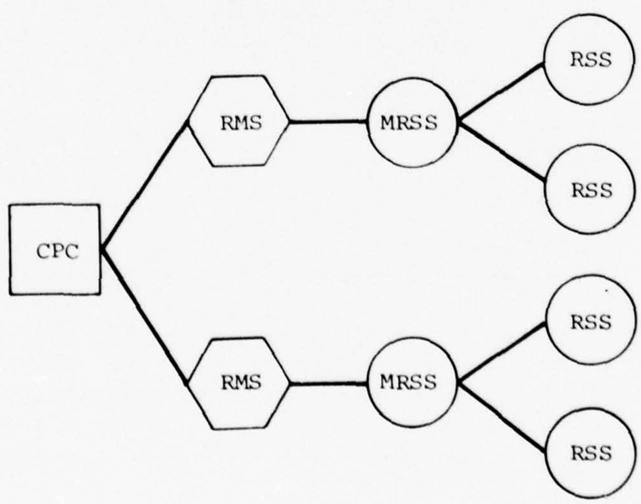
CPC — RMS — MRSS — RSS — RSS — RSS



Series Configuration



RMS Redundancy Configuration



RSS Redundancy Configuration

Figure 5-3. POSSIBLE TACELIS CONFIGURATIONS

CHAPTER SIX

THREE-STATE MODEL FOR RESOLVING DEGRADED OPERATION

The TACELIS system can continue to provide useful tactical support at various levels of degradation. To provide a RAM assessment of TACELIS beyond the usual two-state availability concept, a three-state model is developed in this chapter. The three-state model can be generalized to a more descriptive N state model at a later time if required. The three-state model presented here is sufficient to provide the basis for quantitative evaluation of the steady-state availabilities corresponding to the three levels of TACELIS operation as introduced in Chapter Four of this report.

6.1 MODEL DEVELOPMENT

To illustrate the following discussion, Figure 6-1 depicts the three operational states identified for TACELIS:

- Automated Mode - SEACS function operational
- Manual Mode - Manual tuning necessary
- System Down - Critical function lost

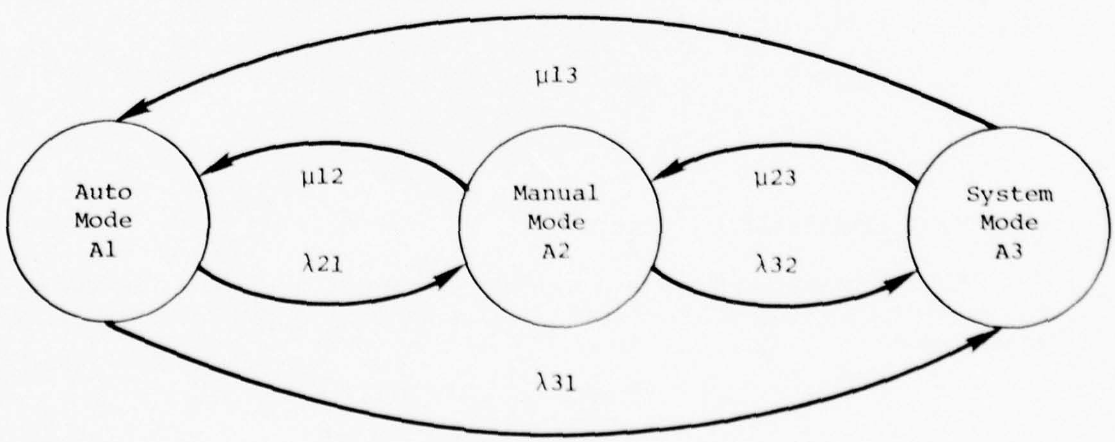


Figure 6-1. TACELIS STATE TRANSITION DIAGRAM

Over a long calendar period, the fractions of time that TACELIS will be in states 1, 2, or 3 (as shown in Figure 6-1) are given by state availabilities A_1, A_2, and A_3. These availabilities are determined by the failure and repair rates of all system components ("components" generally means LRUs).

These component failure and repair rates enter into the formulas for the A_1, A_2, and A_3 in terms of state transition rates λ_{ij}, μ_{ij} where

λ_{ij} = the rate of system degradation from state j to state i

μ_{ij} = the rate of restoration of service from state j to state i

The state transition rates λ_{ij} and μ_{ij} can in theory be developed from the reliability block diagrams of the TACELIS major assemblies when the failure and repair rates of each system component (LRU) are known. This computation is tedious if not computer-automated. In addition, it is difficult (but not impossible) to carry an exact accounting of the uncertainties in the estimates for the many individual LRUs to confidence limits for the transition rates λ_{ij}, μ_{ij} and the state availabilities A_1, A_2, and A_3. The advantage of this direct method of calculating the availabilities is that it permits identification and evaluation of critical components, together with the effects of their failure and repair rates.

An alternative approach is to evaluate the transition rates λ_{ij} and μ_{ij} and the availabilities A_1, A_2, and A_3 directly from the existing developmental testing run logs. Let T_1, T_2, T_3 denote the accumulated operating times TACELIS was in states 1, 2, and 3, respectively, during a total logged operating time $T = T_1 + T_2 + T_3$. Then point estimates of the A_i are

$$\hat{A}_i = T_i/T; \quad i = 1, 2, 3$$

Let n_{ji} denote the logged number of transitions from state i to state j (i, j = 1, 2, 3) during the logged intervals T_1, T_2, and T_3. Then the six transition rates λ_{ji} and μ_{ji} are estimated by

$$\lambda_{ji} = n_{ji}/T_i \qquad i = 1, 2; \; j = 2, 3; \; i \neq j$$

$$\mu_{ji} = n_{ji}/T_i \qquad i = 2, 3; \; j = 1, 2; \; i \neq j$$

6.2 STATE AVAILABILITY FORMULAS

The formulas for the state availabilities A_1, A_2, and A_3 in terms of the transition rates are obtained by solving the steady-state transition equations:

$$\begin{aligned}
0 &= -A_1 \left(\lambda_{21} + \lambda_{31}\right) + A_2\,\mu_{12} + A_3\,\mu_{13} \\
0 &= A_1\,\lambda_{21} - A_2 \left(\lambda_{32} + \mu_{12}\right) + A_3\,\mu_{23} \\
0 &= A_1\,\lambda_{31} + A_2\,\lambda_{32} - A_3 \left(\mu_{23} + \mu_{13}\right)
\end{aligned}$$

subject to the condition that the system must always be in one of the three states, i.e.,

$$A_1 + A_2 + A_3 = 1$$

The solution is seen to be

$$A_1 = {}_1/(\gamma_1 + \gamma_2 + \gamma_3)$$

$$A_2 = {}_2/(\gamma_1 + \gamma_2 + \gamma_3)$$

$$A_3 = {}_3/(\gamma_1 + \gamma_2 + \gamma_3)$$

where, in terms of λ_{ij} and μ_{ij},

$$\gamma_1 = \mu_{12}\,\mu_{13} + \mu_{12}\,\mu_{23} + \mu_{13}\,\lambda_{32}$$

$$\gamma_2 = \mu_{13}\,\lambda_{21} + \mu_{23}\,\lambda_{21} + \mu_{23}\,\lambda_{31}$$

$$\gamma_3 = \mu_{12}\,\lambda_{31} + \lambda_{21}\,\lambda_{32} + \lambda_{31}\,\lambda_{32}$$

6.3 APPLICATIONS OF STATE TRANSITION MODELS

The software applications packages that control TACELIS system operation are currently being modified too frequently to permit acquisition of meaningful data from developmental testing for a three-state availability analysis of the TACELIS system. Since the system is, in effect, being continuously redefined with respect to software, any quantitative description of the availability of the many TACELIS capabilities would be obsolete by the time it could be published. However, at a later state in the development of the TACELIS system, when the hardware and software constituting the system remain constant with time, a multiple-state analysis of TACELIS availability as presented in this chapter should be made. Since several levels of degraded operation can be defined for the TACELIS system, all of which may yield some degree of useful information, the multiple-state analysis provides a much more appropriate description of system availability. Therefore, the methodology has been presented for future use.

CHAPTER SEVEN

RELIABILITY GROWTH

In this chapter, the hardware reliability growth achieved during the first 11 months of developmental testing is analyzed and improvement-effort allocation is discussed.

7.1 RELIABILITY GROWTH

Whenever a statistical estimate is based on a sample of n data items, such as an MTBF estimate based on n incident reports, the confidence that the true but unknown mean of an infinite population of these data items lies within fixed bounds about the estimate increases as n increases. Correspondingly, for a given level of confidence, the bounded interval about the estimate that can be assumed to contain the true but unknown mean decreases in size as n increases. In short, a reasonable number of incident reports must be available to make a meaningful estimate of MTBF and to make statements about reliability growth. Therefore, only those Line Replaceable Units for which more than 15 incidents were reported have been studied to determine whether any significant change in MTBF occurred during the first 11 months of developmental testing.

The analytic approach involved computing a value MTBF(1) for each LRU based on the first half of the calendar test time, which contains all those incidents reported through April 11, 1978. Symmetrical 80 percent confidence limits were developed for the MTBF(1) estimate of the true but unknown mean life of the LRU type (see Figure 7-1). Then a value MTBF(2) was calculated from the second half of the chronological test data. If the MTBF(2) value lay within the 80 percent confidence interval about MTBF(1), the result was judged inconclusive. If the MTBF(2) value lay outside the bounds of the 80 percent confidence interval about MTBF(1), a significant change was recorded. The results of these calculations are presented in Table 7-1. When this analytic method is used, four of the seven unit types show improvement. Two units types have declined in reliability. The results for the VHF Receiver are inconclusive.

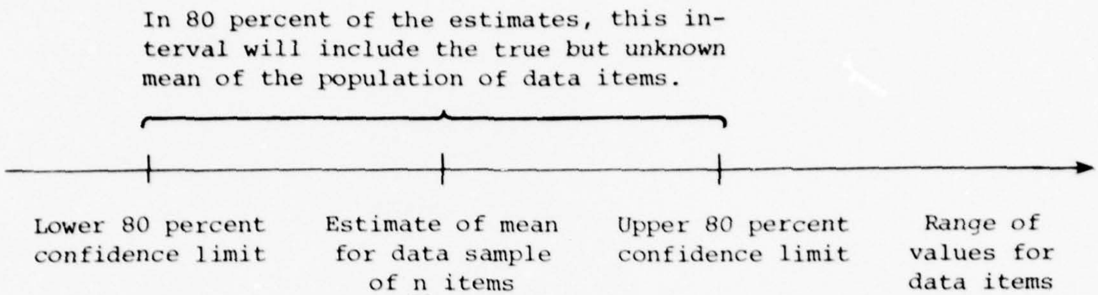
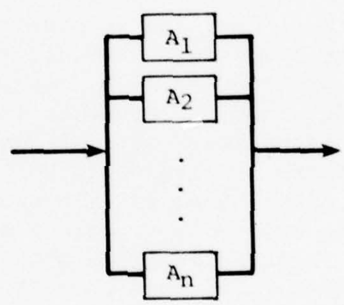


Figure 7-1. CONCEPT OF CONFIDENCE LIMITS

7.2 LRU IMPACT ON TACELIS SYSTEM RELIABILITY

For any integer $\underline{n}$, the following configuration is always more reliable than the single unit A:



The reliability diagrams in Figures 4-1, 4-2, and 4-3 show that the TACELIS system, with first-level capability and one RSS operational, can be no less reliable than 118 units all in series, with

- 66 units in the CPC
- 29 units in the RMS
- 23 units in the RSS

If each unit in this hypothetical series configuration were required to have a 24-hour mission reliability of R_0 or greater, then the reliability of the imaginary system would be

$$R \geq (R_0)^{118}$$

Therefore, by selecting all the LRUs from the equipment list with a 24-hour reliability less than R_0 and accounting for them, one can quickly identify areas for hardware improvement that would guarantee a TACELIS CPC-RMS-RSS sequence to have a 24-hour reliability of *at least* $(R_0)^{118}$.

Table 7-1. MTBF TRENDS FOR HARDWARE UNITS

Unit Type	Lower 80% Confidence Limit for MTBF(1)	MTBF(1) First Estimate	Upper 80% Confidence Limit for MTBF(1)	MTBF(2) Second Estimate	Significance
Temporary Storage Recorder	442.9	484.1	528.3	935.6	Reliability growth
CRT Display Controller	1897.4	2421.5	3054.6	3930.7	Reliability growth
VHF Receiver (1850)	3564.4	4788.0	6327.3	3859.2	Inconclusive
Output Encoder Module	1427.3	2052.0	2789.3	3216.0	Reliability growth
Output Decoder Module	3822.2	8512.0	14633.8	1429.3	Reliability decline
Scanner Control Panel	2982.9	5016.0	7541.2	2948.0	Reliability decline
Function Button Panel	4558.1	7022.4	10002.7	11792.0	Reliability growth

Those LRUs which are the poorest contributors to system reliability can be identified by the process of elimination. The lower cutoff point R_0 for acceptable unit reliability is identified and those LRUs failing to exceed this value are listed. The unit types that are not included in the 118 segments critical to the definition of system success are deleted from the list. Reliability is calculated for each of the critical segments containing LRU types that fail to meet the R_0 standard. Those segments which meet the R_0 value because of unit redundancy are dropped from consideration. The remaining segments are analyzed for allocation of the improvement effort.

Table 7-2 lists LRUs in the TACELIS system having a 24-hour unit reliability of less than .995. The Cartridge Magnetic Tape Unit has been replaced during developmental testing with a more reliable tape-read system. Units judged as being not critical to TACELIS system operation are:

- GRC-103 AM-3349
- GRC-103 RT-662
- Pan Monitor Switch S-2109
- Pan Processor Unit MX-9428
- VHF Receiver 1850

The following units appear as redundant implementations:

- CRT Display Controller
- TD-203 Multiplexer
- Scanner Control Panel
- Time Division Demultiplexer
- Temporary Storage Recorder
- Output Encoder Module
- Output Decoder Module
- Magnetic Tape Drive

Each of the redundant implementations of these units is equivalent to a single unit having greater than .995 24-hour reliability in the currently used assembly configurations.

The following units have not been eliminated from consideration and are critical to system operation:

- 1 LOB Antenna in the RSS
- 1 Twin-Channel Receiver in the RSS
- 1 RAMTEK Keyboard at the Location Analyst position in the CPC

Any improvement in the reliability of these three units types will result in a directly proportional improvement in system reliability.

Table 7-2. TACELIS UNITS HAVING LOWEST RELIABILITY	
Unit	24-Hour Reliability
LOB Antennas	.9883
Cartridge Magnetic Tape Unit	.9888
CRT Display Controller	.9920
GRC-103 AM-3349	.9927
GRC-103 RT-662	.9927
Multiplexer TD-203	.9944
Pan Monitor Switch S-2109	.9925
RAMTEK Keyboard GX-100-A	.9814
Scanner Control Panel C-9112	.9939
Time Division Demultiplexer TD-1099	.9944
Temporary Storage Recorder	.9631
Output Encoder Module	.9909
Output Decoder Module	.9902
Pan Processor Unit MX-9428	.9948
VHF Receiver R-1850	.9944
ULR/17 Twin Channel Receiver R-1982	.9906
Magnetic Tape Drive	.9870

A more rigorous mathematical technique would be to use the equations for R_{CPC}, R_{RMS}, and R_{RSS} developed in Chapter Four to compute the partial derivatives of the assembly reliability values with respect to the reliability of each critical LRU. The method presented in this section, however, is a quick and efficient way to detect trends during developmental testing.

7.3 ANALYSIS OF ASSEMBLY SEGMENTS

The effect of improvement-effort allocation on assembly reliability will now be studied in accordance with the discussion of sensitivity analysis presented in Section 4.7. The segment of the Control and Processing Center containing the 1840 Magnetic Tape Drive has been selected for study. This unit was allocated a very low MTBF in view of the assumption that two units were operating in the CPC for a total of 6,408 test hours, and seven failures were reported. The segment of the assembly being considered is shown in Figure 7-2.

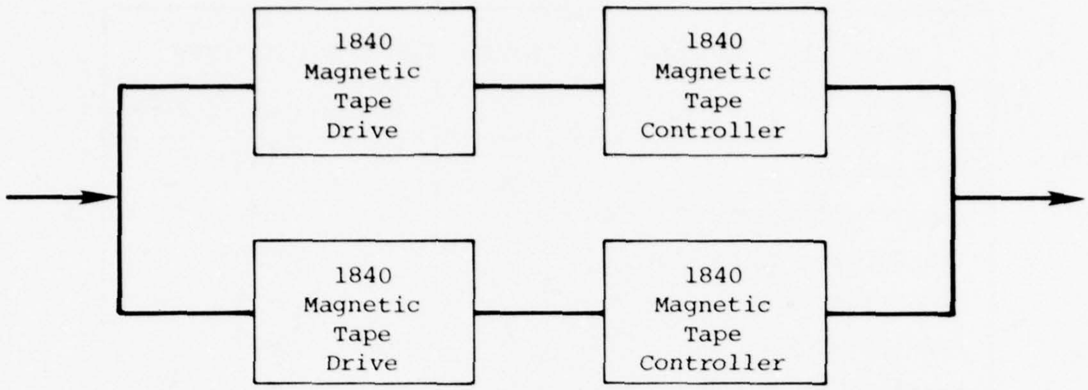


Figure 7-2. SEGMENT OF CPC ASSEMBLY

Figure 7-3 illustrates the reliability of the Magnetic Tape Drive segment of the CPC assembly. Curves are given to show varying degrees, M, of redundancy. The solid curves show reliability as a function of time for one path, two parallel paths, and three parallel paths. The dashed curves show the reliability that would be achieved in each case if the MTBF value for the 1840 Magnetic Tape Drive could be improved from 1830.9 hours to 2000 hours. This graph indicates the improved segment reliability that can be achieved by increasing unit MTBF or implementing redundancy.

In general, graphs similar to Figure 7-3 should be prepared for units with low MTBF values that have a severe impact on system reliability during developmental testing of a system. These graphs should illustrate how various levels of redundancy would improve the reliability of the critical system segment. The impact of improving the MTBF values for elements within the system segment should also be shown. Reliability-improvement effort would be allocated on the basis of a study of these graphs and include such considerations as cost, available space, and whether the critical element was GFE or CFE.

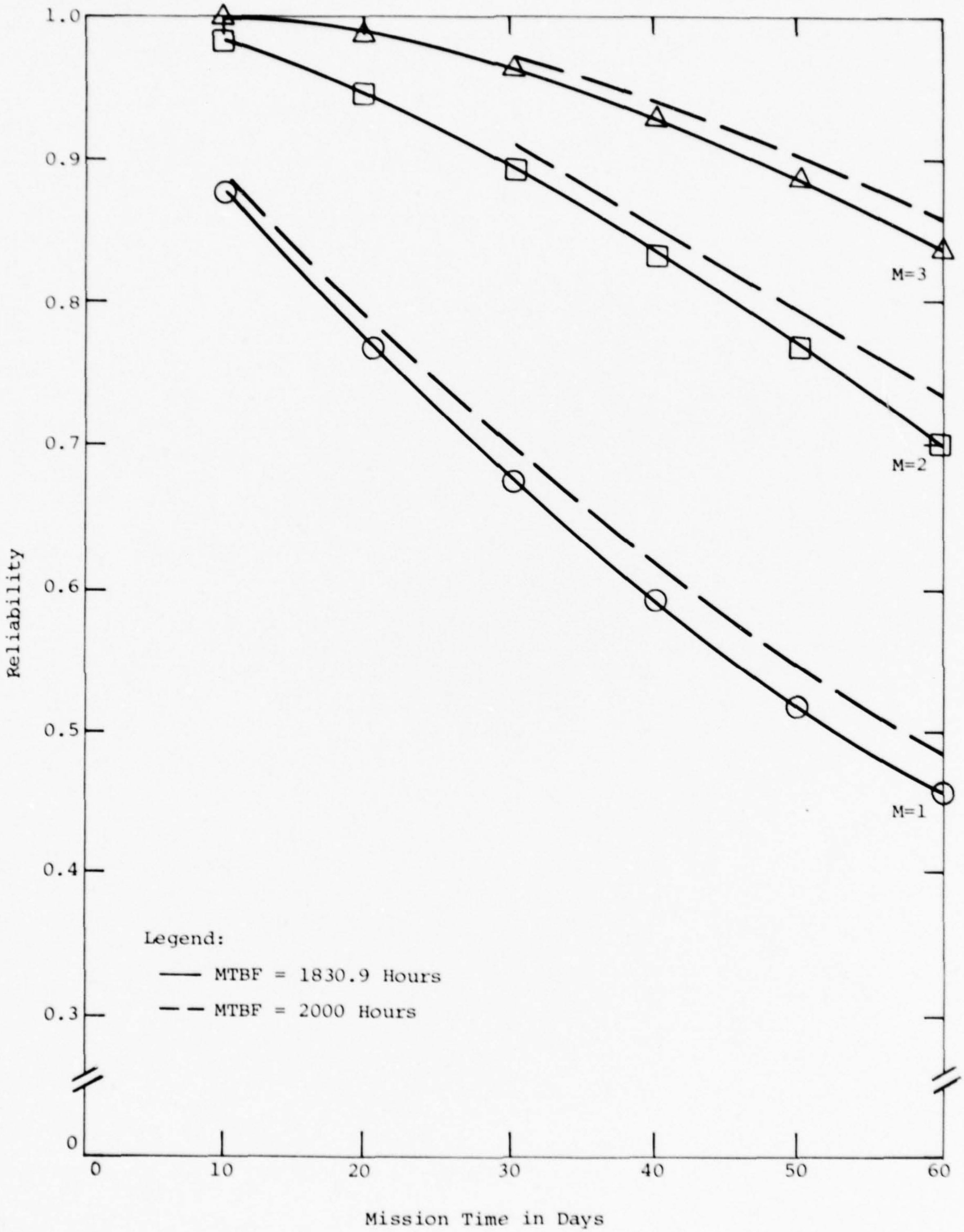


Figure 7-3. MAGNETIC TAPE DRIVE RELIABILITY AS A FUNCTION OF REDUNDANCY, M, AND MTBF IMPROVEMENT

CHAPTER EIGHT

SUGGESTED CHANGES TO IMPROVE RELIABILITY ASSESSMENT

This chapter enumerates the limitations encountered by ARINC Research during analysis of data recorded in the format currently used by the Developmental Tester. Recommendations for improving reliability documentation are also discussed.

8.1 CURRENT METHODS

Reliability data for systems undergoing developmental testing are currently collected by the Developmental Tester. Data are manipulated and stored by a combination of clerical and computerized methods during testing. After the information has been evaluated and categorized at a scoring conference, selected data are subjected to computer analysis to generate reliability values.

The fundamental data set on which the reliability analysis is based consists of all the controlled maintenance actions requested in conjunction with developmental testing. For each occurrence, test personnel fill out a Maintenance Request, DA Form 2407 (illustrated in Figure 8-1). After additional facts become available from subsequent diagnosis and maintenance action, the maintenance data are edited by the Test Engineer for the Developmental Tester and compiled on an Equipment Performance Report, DARCOM Form 2134. This is the form that is actually presented for evaluation at the scoring conference.

The scoring conference participants are tasked with composing the final list of incidents that meet the standard definition of failure and categorizing this list in two ways:

- Separating system from mission failures
- Distinguishing between failures attributable to Government-furnished equipment and contractor-supplied items

The final data set, which results from editing of the original data by the Test Engineer and categorizing of the edited data by the scoring conferees, is used to generate reliability values.

USE TYPEWRITER OR PRINT FIRMLY ON HARD SURFACE WITH HARD PENCIL OR BALL POINT PEN

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MAINTENANCE REQUEST For use of this form, see TM 38-750; the proponent agency is Office of the Deputy Chief of Staff for Logistics	* See reverse of for copy for codes and additional data	PAGE NO	NO. OF PAGES	REPORTS CONTROL SYMBOL CSGLD-1047 (R1)

SECTION I ☐ WORK REQUEST ☐ MWO ☐ EIR ☐ ORGANIZATION ISSUE PRIORITY DESIGNATOR CODE

CONTROL NUMBER	1a. ORGANIZATION	b. LOCATION	c. UNIT IDEN CODE
C14165			

2. SERIAL NUMBER	3. NOUN NOMENCLATURE	4. LINE NUMBER	5. MODEL	6. NATIONAL STOCK NUMBER

7. MAINTENANCE ACTIVITY	8. UTILIZATION CODE*	9. SELECTED ITEM	10. HOURS	11. MILES	12. ROUNDS	13. STARTS
	☐	☐ Y YES ☐ N NO				

14. FAILURE DETECTED DURING (Select one - use √ or X)

☐ A SCHEDULED MAINTENANCE ☐ C TEST ☐ E STORAGE ☐ G FLIGHT
☐ B HANDLING ☐ D NORMAL OPERATION ☐ F INSPECTION ☐ H OTHER

15. FIRST INDICATION OF TROUBLE (Select one - use √ or X)

☐ 048 INOPERATIVE ☐ 256 OVERHEATING ☐ 790 OUT OF ADJUSTMENT
☐ 006 NOISY ☐ 367 LOW PERFORMANCE ☐ OTHER

16. DESCRIBE DEFICIENCIES OR SYMPTOMS ON THE BASIS OF COMPLETE CHECKOUT AND DIAGNOSTIC PROCEDURE IN EQUIPMENT TM (Do not prescribe repairs)

PRIOR TO USING THIS FORM READ CAREFULLY THE STEP BY STEP INSTRUCTIONS IN TM 38-750.

USES AND INSTRUCTIONS

1. When all appropriate entries are made in Section I, THIS FORM BECOMES A FORM PECULIAR to a specific weapon system, item of equipment or its component or separate assembly, or a group of similar items with the same FSN. This Section, when combined with either Section II or III or a combination of all three, provides the basis for controlled maintenance a ons. This form will be used for:

AT THE ORGANIZATIONAL LEVEL

a. Requesting repairs and maintenance services.
b. Reporting accomplishment of Modification Work Orders.
c. Submission of Equipment Improvement Recommendations (EIR).
d. Reporting receipt of defective materiel.
e. It may be used to record maintenance accomplishments.

AT SUPPORT MAINTENANCE LEVEL

a. Recording maintenance work and/or service actually performed.
b. Reporting the installation of equipment modifications.
c. Submission of Equipment Improvement Recommendations (EIR).
d. Requesting repair of unserviceable components, assemblies and subassemblies as a result of direct exchange procedures.
e. Reporting receipt of defective materiel.
f. Requesting maintenance work and/or services between shops of a given field maintenance shop (Intra-Shop Maintenance Request).
g. Requesting maintenance work and/or services of another field maintenance unit or activity within the same echelon or at a hi echelon (Inter-Shop Maintenance Request).

AT DEPOT MAINTENANCE LEVEL

a. Reporting the installation of equipment modifications.
b. Submission of Equipment Improvement Recommendations (EIR).

2. SUBMITTING SEPARATE EQUIPMENT IMPROVEMENT RECOMMENDATIONS (EIR's)

a. EMERGENCY EIR's will be submitted to the designated Department of the Army agency by electrical message. A follow-up DA Form 2407, checked "Emergency" in Section III will be submitted with the message number indicated as part of the narrative remarks in Block 35.
b. URGENT EIR's will be air-mailed to the designated Department of the Army agency. Check "Urgent" in Section III.
c. ROUTINE EIR's prepared as a separate action will require only normal mailing of the NMP Copy 2 to the designated Department of the Army agency. Check "Routine" in Section III.

23. SUBMITTED BY	24. RECEIVED BY
JULIAN DATE	JULIAN DATE

SECTION III - EQUIPMENT IMPROVEMENT RECOMMENDATION

29. NORMAL REPLACEMENT (Select one - use √ or X)	30. EIR (Select one - use √ or X)	31. RECOMMENDATION (Select one - use √ or X)	32. a. ORGANIZATION/ACTIVITY	c. UNIT IDEN CODE
☐ Y YES	☐ E EMERGENCY	☐ A IMPROVE DESIGN ☐ REVISE PROCEDURE	b. LOCATION	d. SUBMITTED BY
☐ N NO	☐ U URGENT ☐ R ROUTINE	☐ D MODIFY ☐ OTHER (Specify)		

33. NATIONAL STOCK NUMBER	34. NOUN NOMENCLATURE	35. OPINION OR REMARKS. DESCRIBE CONDITIONS UNDER WHICH FAILURE OCCURRED. ATTACH PHOTOS OR SKETCHES, IF AVAILABLE.

DA FORM 1 OCT 73 2407 EDITION OF 1 JAN 64 WILL BE USED UNTIL EXHAUSTED. RECEIPT COPY 1

(continued)

Figure 8-1. MAINTENANCE REQUEST FORM

FAILURE CODE

CODE	DESCRIPTION
	NON AERONAUTICAL EQUIPMENT
717	Accident Damage
127	Adjustment, Improper
031	Alignment, Improper
713	Battle Damage
070	Broken (includes cracked, cut, torn, punctured)
900	Burned (includes blistered, corroded, scored, shorted, grounded)
910	Chipped (includes flaking, dented, pitted, grooved, nicked, stripped, frayed)
180	Clogged (includes pinched, jammed, seized, locked, binding)
027	Collapsed (includes buckled, warped, bent, sprung)
230	Dirty (includes contaminated)
235	Dry
916	Impending or incipient failure indicated by spectrometric oil analysis
381	Leaking (includes seeping)
730	Loose (includes unstable)
500	Lubrication (includes over under)
750	Missing
807	No Defect: Equipment (previously modified) restored to original configuration when authorized by DAMWO
799	No Defect (includes component removed and reinstalled to facilitate other maintenance, MWO not applicable, partial MWO compliance, removed for scheduled maintenance, removed for time change, removed for troubleshooting)
801	No Defect: MWO compliance
797	No Defect: MWO previously complied with
920	Not Determined
450	Open
250	Oversize
275	Undersize
627	Wet
020	Worn Excessively (includes deteriorated)
950	Wrong Part
	AERONAUTICAL EQUIPMENT
717	Accident Damage
082	Air leak
178	Airstart Failure
031	Alignment Improper
007	Arcing, Arced
101	Armature Dirty
693	Audio Faulty
129	Backfiring
104	Backlash Improper
731	Battle Damage
710	Bearing Failure
780	Bent/Dented
673	Beyond Specification Tolerance
135	Binding (Friction Excessive, Seized)
053	Blistered
590	Bounce Time, Excessive
060	Brittle
070	Broken/Fractured
108	Broken or Missing Safety Wire or Key
720	Brush Failure/Worn Excessively
109	Buckled
900	Burned (Charred)
171	Burred
111	Burst (Exploded)
469	Bushing Failure
024	Calibration Incorrect
574	Cannibalization
910	Chipped (Nicked)
180	Clogged
076	Cold Solder Joint
160	Contact/Connection Defective
306	Contamination, Fuel
308	Contamination, Oil
111	Controls, Inoperative
344	Corona Effect
170	Corroded
190	Cracked
575	Crash Damage
845	Crystallized
329	Current Incorrect
116	Cut/Torn
763	Damaged for Test Purposes
210	Detent Action Poor
968	Dripping
118	Disconnected/Disengaged
201	Distorted
235	Dry
293	Electrical Power Loss (Aircraft)
231	Elongated
232	End Play Excessive
147	Engine Removed, Excess Maintenance
234	Excessive G Forces
190	Fails Diagnostic/Automatic Tests
351	Fails to Tune or Drifts
402	Failure Caused by Other Component Failure
781	Faulty Reading
755	Feedback Incorrect
255	Flaking
369	Flame Out

FAILURE CODE

CODE	DESCRIPTION
037	Fluctuates, Unstable
101	Foreign Object Damage
748	Frequency Erratic or Incorrect
179	Fuel Pressure Incorrect
200	Fungus Effect
477	Fuse Blown
061	Fused
001	Gassy
214	Grooved
300	Grounded Electrically
311	Hard Landing
655	Heat Damage
370	High Voltage Breakdown
065	High VSWR
079	Hot Firing Damage
317	Hot Start
829	Hunting Head
740	Icing
916	Impending or incipient Failure Indicated by Spectrometric Oil Analysis
703	Improper Amplitude
627	Improper Attenuation
688	Improper Change Response
738	Improper Fit
629	Improper Source Output
088	Incorrect Gain
864	Incorrect Modulation
166	Incorrect Voltage
750	Insulation Breakdown
081	Interference
374	Internal Failure
370	Jammed
381	Leaking (Liquid)
382	Liquid/Vapor Lock
383	Lock On Malfunction
730	Loose
181	Low Compression
084	Low CM or Emission
962	Low Power (Electronic)
537	Low Power or Thrust
752	Lubrication Omitted
979	Maintenance Error
688	Manifold Pressure Beyond Limits
225	Manufacturer Defect
344	Melted
372	Metal on Magnetic Plug
300	Microphonic
253	Misfires
750	Missing
908	Miswired
420	Moisture Saturation (Wet, Contaminated)
799	No Defect
800	No Defect: Component Removal/Reinstalled to Facilitate Other Maintenance
801	No Defect: MWO Compliance
802	No Defect: MWO Partially Applied
798	No Defect: MWO Not Applicable
797	No Defect: MWO Previously Complied With
804	No Defect: Removed for Scheduled Maintenance (includes Mandatory Inspections)
803	No Defect: Removed for Time Change
305	No Fuel Cutoff
367	No Indicating Light
008	Noisy (Chattering)
022	No Oscillation
255	No Output/Incorrect Output
296	Oil Breathing Excessive
198	Oil Consumption Excessive
601	Oil in Induction System
605	Oil Pressure Incorrect
458	Open
003	Open Filament Tube Circuit
437	Operating Error
857	Oscillating
799	Out of Adjustment
461	Output Too High
021	Overheated
500	Overlubricated
464	Overspeed
127	Pinched/Flattened/Collapsed
570	Pitted
530	Polarity Reversed
261	Poor Bonding (Delaminated)
564	Poor Spectrum
677	Pressure Incorrect
540	Puncture
176	Rate of Feather Slow
567	Resistance High
568	Resistance Low
714	Rise Time Incorrect
324	RPM Beta Governing Faulty
315	RPM Fluctuation/Incorrect
740	Saturation Resistance High
473	[illegible]
801	Servo Mag Amp Time Constant
585	Sheared
176	Shorted or Grounded
630	Shorted to Secondary
140	Shrinkage
163	Slip Ring or Commutator Failure

FAILURE CODE

CODE	DESCRIPTION
314	Slow Acceleration
318	Slow Deceleration
158	Smoking
279	Spray Pattern Defective
115	Sprung
513	Stalls - Compressor
329	Starting Stall
650	Sticky
749	Storage Time Incorrect
568	Stripped
945	Structural Failure
503	Sudden Stop
519	Surged
649	Sweep Malfunction
695	Sync Absent or Incorrect
334	Temperature Incorrect
018	Tested OK, Did Not Work
274	Timing Off
379	Tooth Broken on Gear
563	Torque Incorrect
816	Total Impedance, High
817	Total Impedance, Low
877	Transportation Damage
666	Twisted
561	Unable to Adjust Limits
670	Unbalanced
680	Unstable
690	Vibration Excessive
682	Video Faulty
725	Weld Cracked or Broken
020	Worn Excessively
950	Wrong Part

UTILIZATION CODE

CODE	DESCRIPTION
0R	Active Army (except as otherwise listed)
1	Depot Stock
2	Post Supply Activities, Class I Installations
3	Post Supply Activities, Class II Installations
4	Operational Readiness Float (ORF)
5	Repair and Utilities
6	ARADCOM Units
7	Army National Guard, Except Equipment Pools
8	Army National Guard, Equipment Pools
9	Air Force National Guard Units
A	Army Reserve Units, Except Equipment Pools
B	Army Reserve Units, Equipment Pools
C	Air Force Reserve
D	Army ROTC
E	Air Force ROTC
F	U.C. CONARC (All TOE units assigned direct CG CONARC)
G	Defense Atomic Support Agency
H	Army Security Agency
J	Defense Communications Security Agency
K	U.S. Army Combat Developments Command
L	U.S. Army Test and Evaluation Command
M	Labor Service Units
N	Preposition Stock
P	Depot Installation Equipment
Q	Equipment assigned to service schools and training centers
R	Military Assistance Program (MAP)
S	Overhaul Facility, Military
T	Overhaul Facility, Commercial
U	Manufacturing Facility
X	Repair Cycle Float (RCF)
Y	U.S. Army Intelligence Command

ACTION CODE

CODE	DESCRIPTION	CODE	DESCRIPTION
A	Replaced	U	ORF Exchange
B	Adjusted	W	Hour Meter/Odometer Change
C	Repaired	X	Gun/Howitzer Tube Change
E	Serviced (except aircraft)	Y	ORF No. Stocked
F	Initial Inspection	0R	Modification by Replacement
G	Final Inspection	1	Service: Scheduled (aircraft only)
H	MWO	2	Service: Unscheduled (aircraft only)
J	Tested	3	Preventive Maintenance: Daily (aircraft only)
K	No ORF	4	Preventive Maintenance: Intermediate (aircraft only)
L	Removed and Installed	5	Preventive Maintenance: Periodic (aircraft only)
M	Checked NRTS	6	Special Inspection (aircraft only)
N	Checked Not Repairable	7	Ground Handling (aircraft only)
P	Checked Serviceable		
R	Removed		
S	Installed		
T	TB Compliance		

TIME CONVERSION CODE

MINUTES	TENTHS	MINUTES	TENTHS
1-6	1	31-36	6
7-12	2	37-42	7
13-18	3	43-48	8
19-24	4	49-54	9
25-30	5	55-60	Full hour

Figure 8-1. (continued)

8.2 INFORMATION LOSS

The clerical methods currently used for data processing may reasonably be applied to systems having a simple configuration or to systems requiring few maintenance actions. For systems composed of several different generic LRU types and for systems that require numerous maintenance actions, more efficient data processing methods are needed. To choose between clerical and computerized methods, a decision should be made based on the number of different LRU types included in the system and the total number of maintenance actions requested during the first month of developmental testing. For example, automated data processing might be recommended for systems composed of more than 50 different generic LRU types or for systems that are expected to require more than 200 maintenance actions during developmental testing.

Information that would have been useful for the TACELIS reliability assessment has been lost primarily in three ways:

- By failure to record all data of importance initially on the Maintenance Request
- By routine omission of data not currently included in the reliability assessment when data are being compiled on the Equipment Performance Report
- By obscuring significant data trends in the clerical manipulation of data

Each of these problem areas will be discussed in detail in the following sections.

8.3 DATA COLLECTION

To extract the maximum possible reliability information from the test experience, the history of each part used in the system being tested throughout both functional deployment and incurred maintenance must be retrievable from the recorded data. This is possible if the following two conventions are observed:

- The configuration of the system at the inception of testing must be completely described, stating a unique LRU type and the unit serial number corresponding to each address in the configuration.
- For each incident recorded, all of the following information must be obtained:
    - LRU type (usually denoted by part number)
    - Serial number
    - Location within system
    - Time of occurrence
    - LRU type of replacement, if any
    - Serial number of replacement, if any

When all this necessary information is available, a variety of data sorts can be performed that may reveal data trends pertinent to reliability improvement studies. Two examples of information loss of this type are displayed in Figure 8-2. One Equipment Performance Report describes the removal of one of the 32 Temporary Storage Recorders in the system. The other report documents an incident involving one of the eight Recorder Control Modules deployed. Neither report gives a serial number.

8.4 DATA EDITING

One important category of information routinely omitted in compiling data on Equipment Performance Reports is time-related data. For every reported incident at least two time values should be recorded:

- The time required to restore the functional capability through replacement or on-site repair
- The time required to repair the LRU if it is removed and replaced by a similar unit

The absence of these data prevents calculation of MTTR for each LRU in the TACELIS system. These data, if obtainable, would provide valuable RAM information.

Another difficulty inherent in the present clerical methodology results from the fact that several incidents may be included on one Equipment Performance Report. In most cases, such reporting includes only incidents relating to one type of LRU, characterized by a common part number but including more than one serial number. A one-to-one correspondence between each incident and its recorded data item set is necessary before any automated data processing method can be applied. Figure 8-3 is a typical Equipment Performance Report grouping several reported incidents on one form.

8.5 DATA MANIPULATION

A number of data sorting processes may be used to expose data trends of interest, both for reliability growth analysis and for improvement-effort allocation:

- Time history of one particular unit by serial number
- Incident record of one LRU type by part number
- Reliability of one LRU type as a function of time
- Incidents grouped by deployment location

EQUIPMENT PERFORMANCE REPORT
(DARCOM, AMCR 702-38)

DATE: 15 Dec 77
OFFICE SYMBOL: STEEP-MT-AE

TO:

FROM: US Army Electronic Proving Ground
Chief, EWI Test Branch
STEEP-MT-A
Ft Huachuca, AZ 85613

1. EPR NO.:	2. TECOM/AVSCOM PROJ NO.:	3. TEST TITLE:
KH-161	6-EE-TSQ-112-001	AN/TSQ-112 (TACELIS) DT-II

I MAJOR ITEM DATA

4. MODEL: AN/TSQ-112 (TACELIS)	5. SERIAL NO.: N/A
6. QUANTITY: 1 each	7. LIFE PERIOD: N/A
8. MFR: GTE SYLVANIA	9. USA NO.: NA

II PART DATA

10. NOMENCLATURE DESCRIPTION: Temporary Storage Recorder	
11. FSN: N/A	12. MFR PART NO.: RD-369/U
13. DRAWING NO.: N/A	14. MFR: Emerson Electronics
15. QUANTITY: 1	16. NEXT ASSEMBLY: Recorder Control Module
17. MAC FUNCTIONAL GRP: N/A	18. PART TEST LIFE: 1344

III INCIDENT DATA

19. DATE OF OCCURRENCE: 6 Dec 77		20. TYPE OF REPORT:	21. ACTION TAKEN:
22. MAINT SPT. SUM. CODE: RAM		X a. INCIDENT	a. REPLACED
23. OBSERVED DURING:	24. TEST ENVIRONMENT:	b. INFORMATION	b. REPAIRED
X a. OPERATION	Ambient	25. INCIDENT CLASSIFICATION:	c. ADJUSTED
b. MAINTENANCE		a. CRITICAL	d. DISCONNECTED
c. INSPECTION		b. MAJOR	X e. REMOVED
d. OTHER		X c. MINOR	f. NONE

IV INCIDENT DESCRIPTION

26. DESCRIBE INCIDENT FULLY (INCLUDE IMPACT OF INCIDENT ON MAC CODE IDENTIFIED IN BLOCK 22.)

1. The Temporary Storage Recorder would not stop at EOT/BOT marker. The unit was removed and sent to intermediate maintenance.

2. The incident occurred during the Power Requirements test.

3. Impact on testing was minimal since the item was not required for ongoing tests.

4. The level of maintenance required for removal was organizational.

INCIDENT CLASSIFICATION IS SUBJECT TO RECLASSIFICATION

27. DEFECTIVE MATERIAL SENT TO: Intermediate

28. NAME, TITLE & TEL EXT OF PREPARER:	29. FOR THE COMMANDER:
MARK REISER Electronics Engineer AV 879-3260	H.R. Lung H.R. LUNG Chief, EWI Test Branch

DARCOM FORM 2134 — *Previous edition may be used until exhausted.*

(continued)

Figure 8-2. EXAMPLE OF INFORMATION LOSS ON TWO EPR FORMS

EQUIPMENT PERFORMANCE REPORT (DARCOM/AMCR 700-38)	DATE: 25 Jan 78
	OFFICE SYMBOL: STEEP-MT-AE

TO:	FROM: US Army Electronic Proving Ground Chief, EWI Test Branch STEEP-MT-A Ft Huachuca, AZ 85613

1. EPR NO.: KH- 251	2. TECOM/AVSCOM PROJ NO.: 6-EE-TSQ-112-001	3. TEST TITLE: AN/TSQ-112 (TACELIS) DT-II

I MAJOR ITEM DATA

4. MODEL: AN/TSQ-112 (TACELIS)	5. SERIAL NO.: N/A
6. QUANTITY: 1 each	7. LIFE PERIOD: N/A
8. MFR: GTE Sylvania	9. USA NO.: NA

II PART DATA

10. NOMENCLATURE DESCRIPTION: Recorder Control Module	
11. FSN: N/A	12. MFR PART NO.: NA
13. DRAWING NO.: N/A	14. MFR: Emerson Electronics
15. QUANTITY: 1	16. NEXT ASSEMBLY: Scanner Control Panel
17. MAC FUNCTIONAL GRP: N/A	18. PART TEST LIFE: 2544

III INCIDENT DATA

19. DATE OF OCCURRENCE: 25 Jan 78	20. TYPE OF REPORT:	21. ACTION TAKEN:
22. MAINT SPT. ELM. CODE: RAM	X a. INCIDENT	a. REPLACED
23. OBSERVED DURING: / 24. TEST ENVIRONMENT:	b. INFORMATION	b. REPAIRED
X a. OPERATION / Ambient	25. INCIDENT CLASSIFICATION:	c. ADJUSTED
b. MAINTENANCE	a. CRITICAL	d. DISCONNECTED
c. INSPECTION	b. MAJOR	e. REMOVED
d. OTHER	X c. MINOR	X f. NONE

IV INCIDENT DESCRIPTION

26. DESCRIBE INCIDENT FULLY (INCLUDE IMPACT OF INCIDENT ON MAC CODE IDENTIFIED IN BLOCK 22):

1. The Recorder Control Module could not control the appropriate Temporary Storage Recorders. Intermediate maintenance was notified.

2. The incident occurred during TACJAM interface testing.

3. The impact on testing was minimal as the item was not required for ongoing tests.

4. The level of maintenance required for isolation was organizational.

INCIDENT CLASSIFICATION IS SUBJECT TO RECLASSIFICATION

27. DEFECTIVE MATERIAL SENT TO: NA

28. NAME, TITLE & TEL EXT OF PREPARER:	29. FOR THE COMMANDER:
MARK REISER Electronics Engineer AV 879-3260	H.R. Lung H.R. LUNG Chief, EWI Test Branch

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Figure 8-2. (continued)

EQUIPMENT PERFORMANCE REPORT
(DARCOM, AMCR 702-38)

DATE: 13 Jan 78	OFFICE SYMBOL: STEEP-MT-AE

TO:	FROM: US Army Electronic Proving Ground Chief, EWI Test Branch STEEP-MT-A Ft Huachuca, AZ 85613

1. EPR NO.:	2. TECOM/AVSCOM PROJ NO.:	3. TEST TITLE
KH-210	6-EE-TSQ-112-001	AN/TSQ-112 (TACELIS) DT-II

I MAJOR ITEM DATA

4. MODEL AN/TSQ-112 (TACELIS)	5. SERIAL NO.: N/A
6. QUANTITY: 1 each	7. LIFE PERIOD: N/A
8. MFR: GTE Sylvania	9. USA NO.: NA

II PART DATA

10. NOMENCLATURE DESCRIPTION: Temporary Storage Recorders	
11. FSN: N/A	12. MFR PART NO.: RD-369/U
13. DRAWING NO.: N/A	14. MFR: Cincinnati Electronics
15. QUANTITY: 1	16. NEXT ASSEMBLY: Recorder Control Module
17. MAC FUNCTIONAL GRP: N/A	18. PART TEST LIFE: 2160 hrs

III INCIDENT DATA

19. DATE OF OCCURRENCE: 9 Jan 78	20. TYPE OF REPORT:	21. ACTION TAKEN:
22. MAINT SPT, ELM, CODE: RAM	X a. INCIDENT	a. REPLACED
23. OBSERVED DURING: / 24. TEST ENVIRONMENT:	b. INFORMATION	b. REPAIRED
a. OPERATION / Ambient	25. INCIDENT CLASSIFICATION:	c. ADJUSTED
X b. MAINTENANCE	a. CRITICAL	d. DISCONNECTED
c. INSPECTION	b. MAJOR	e. REMOVED
d. OTHER	X c. MINOR	X f. NONE

IV INCIDENT DESCRIPTION

26. DESCRIBE INCIDENT FULLY (INCLUDE IMPACT OF INCIDENT ON MAC CODE IDENTIFIED IN BLOCK 22):

1. Temporary Storage Recorders S/N 107, 132, 109, 118, 111, 104, 117, 126, 129, 121, and 125 were submitted to depot for tachometer and preamplifier modifications. The units were modified, tested, and returned to service.

2. The incident occurred during Line of Bearing Repeatability tests.

3. Impact on testing was minimal as items were not required for ongoing tests.

4. Level of maintenance required for modifications was depot, for removal and reinstallation was organizational.

INCIDENT CLASSIFICATION IS SUBJECT TO RECLASSIFICATION

27. DEFECTIVE MATERIAL SENT TO: NA

28. NAME, TITLE & TEL EXT OF PREPARER:	29. FOR THE COMMANDER:
MARK REISER Electronics Engineer V 879-3260	H.R. Lung H.R. LUNG Chief, EWI Test Branch

DARCOM FORM 2134 — *Previous edition may be used until exhausted.*

Figure 8-3. EXAMPLE OF INCIDENT GROUPING ON ONE EPR FORM

The workload imposed on the Test Engineer by manual data-handling methods precludes this type of data analysis for systems requiring large numbers of maintenance actions. Therefore, data trends of interest may not be revealed.

8.6 IMPROVEMENT REQUIREMENTS

To be advantageous, any changes in reliability documentation methods should conform to certain basic philosophies. The suggested improvements should be sufficiently comprehensive to support both developmental and operational testing with the same set of data-collection and data-analysis tools. They should invoke the powerful algorithmic iteration and list-processing capabilities of the computer. Finally, the effort required to implement new techniques must have a lower dollar and man-hour value than the value of the time and information lost with the present techniques.

8.7 RECOMMENDED METHODOLOGY

The recommended methodology for dealing with test programs that generate large quantities of maintenance requests is keyed to improvement in five basic areas:

- Military Standard RAM concepts and definitions
- The test design and overall test plan
- The incident-reporting format
- The data manipulation techniques
- The agenda for the scoring conference

These concepts must be implemented in a manner that coordinates with a computerized data analysis applicable to the results of both developmental and operational testing.

Computer analysis should begin as soon as 200 incident reports become available from developmental testing. The analysis should be updated periodically to support RAM improvement allocation and reliability growth analysis. At the time of the scoring conference, the same computer capability should be used to develop an agenda for the scoring conference. Finally, the automated analysis should be capable of providing all required RAM statistics based on the results of the scoring conference.

8.8 CONCEPTS AND DEFINITIONS

Before a meaningful RAM analysis procedure can be automated, the discrepancies and ambiguities in the currently published Technical Manuals, Army Regulations, and Military Standards must be resolved. The first effort should be to create a system calendar similar to that shown in Figure 2-1 (Chapter Two) containing all the time divisions necessary to describe the

life of the system, with particular attention to the special practices and procedures of developmental and operational testing. Then the time-related parameters needed for a comprehensive statement of system effectiveness should be defined with reference to the system calendar.

8.9 TEST PLAN

Several improvements are indicated during the planning phase. A program must be developed to provide all test participants with an overview of the information flow from raw test data to final RAM results. This overview is necessary among the participating agencies as well as within each individual agency. The data-collection personnel, the test engineer who clerically manipulates the data, and the analyst who conducts the final computer analysis are currently operating without formal communication, although these participants are within the same (Developmental Testing) agency. This isolation contributes to information loss. Moreover, after 1-1/2 years of TACELIS developmental testing, the Materiel Developer has not been thoroughly briefed by the Developmental Tester on the computer analysis techniques used by the latter agency. The situation urgently requires improved lines of communication.

A complete list of the LRUs to be included in the system under test should be published for the use of all participants prior to testing. This document should present an unambiguous description of each LRU and should indicate in which major assemblies and in what quantities within each assembly a particular LRU type is deployed. This list should be periodically updated to reflect necessary substitutions and component modifications. All personnel involved in the data collection and analysis effort should be working from the same list of LRUs and using the same nomenclature. This is currently not being accomplished, with the result that serious difficulty is encountered in assessing data for improvement-effort allocation prior to the scoring conference.

An initial description of system configuration must be prepared, describing each equipment location as a unique address. The part number and serial number of the physical unit at each address should be specified at the start of testing. Particular attention should be given to preserving the histories of similar equipments in different deployment locations. Only in this way can some failure patterns influenced by maintenance and usage, environmental factors, or collocated faulty equipment be isolated.

It is particularly important that the nomenclature system developed permit a distinction between Government Furnished Equipment (GFE) and Contractor Furnished Equipment (CFE). The majority of the LRUs for which the highest numbers of incidents were reported for this study are GFE (6 out of 7). It must be possible for the computer algorithm to make accurate statements about the impact of CFE on system reliability if improvement effort is to be properly allocated. Therefore, the separate contributions of GFE and CFE to system reliability must be appropriately accounted for.

A run log should be designed to preserve test activity data pertinent to the RAM evaluation. Chronological data -- including Julian date, elapsed total test time, and daily uptime and downtime for major assemblies -- should be recorded in a format directly translatable to computer input. All substitutions, modifications, or reconfigurations should be recorded in this run log, combined with the elapsed total test time at which they are effected. Currently, vendor modifications are reflected only as nomenclature changes in the Equipment Performance Reports. In this way, valuable reliability growth data are lost.

The configuration description, LRU list, and run log formats must be flexible enough to meet the expanded requirements of operational testing.

8.10 INCIDENT REPORTING

Data-collection personnel may be handicapped by several factors:

- Lack of *motivation* because they have no overview of how the data will be used
- Lack of elementary RAM *training* in the meaning and significance of the data
- Lack of *opportunity* to properly complete data forms during a high-workload test situation
- Lack of appropriate *alternatives* for describing a particular situation because of the composition of data forms

All personnel who will participate in data-collection during a planned test should be given a brief training course before testing starts. This course should include motivational statements, a simple but factual description of RAM statistics, and an overview of how the test data will be developed and analyzed. In addition, a human-engineering effort should be directed toward composition of a data-collection format that will obtain the best results. A detailed study of test procedures should be conducted before this comprehensive incident report is designed. A checklist or multiple-choice structure is probably the most appropriate.

A single report form should be designed to accommodate all data relating to one particular incident. It would be used to initiate incident reporting; track all subsequent data, including diagnosis and maintenance efforts; and carry the data to the computer analysis in a format identifiable with the input of the computer program. This procedure is intended to prevent information loss in a manual data-editing step by deferring data editing to a computer sort. The proposed incident report form would replace the Maintenance Request and Equipment Performance Report forms currently used.

To permit timely forwarding of information concerning incidents to the Test Engineer without waiting for the addition of maintenance and repair data, the format would be implemented on multiple copy paper. One copy,

although still incomplete, could be promptly routed to the Test Engineer following incident occurrence. Remaining copies could be distributed to test personnel requiring the data after all maintenance and repair information had been included.

The computer program would be correspondingly designed to process the data in various levels of detail. First-level processing would be applied to data immediately routed to the Test Engineer to support allocation of reliability improvement efforts. More detailed processing would augment the initial RAM results when the completed incident reports became available.

The crucial factor in making this procedure efficient is the description of exactly what constitutes an incident. It is necessary to construct a clear definition of acceptable operation, for both individual units and composite systems, as well as an exact statement defining mission success. Whenever operation fell below this predetermined level of satisfactory performance, an incident report would be generated. The report format should be designed to include parameters that permit computer analysis to distinguish between the following:

- Scheduled and nonscheduled maintenance
- System and mission failures
- GFE and CFE

In the present system, reports are generated during developmental and operational testing for controlled maintenance actions according to the schedule shown on the front of DA Form 2407 (Figure 8-1) entitled "Uses and Instructions". At the scoring conference, failures are categorized according to the Signals Warfare Laboratory publication *Failure Definition and Scoring Criteria*. The data set subjected to the reliability analysis using current methods is initially defined by the maintenance criteria and ultimately sorted by the failure definition, although these two concepts were developed independently. With the recommended methodology, all the definitions by which the data are evaluated during analysis should be tailored to work together.

8.11 COMPUTER PROGRAM

The composition of a computer program that would serve all the requirements of storage, sorting, and analysis of data for developmental and operational testing is the basic element of the recommended methodology. The important characteristic of such a program is *flexibility*.

Multiple READ options must be available to accept the various levels of detail with which incidents would be described, including:

- The incomplete incident descriptions forwarded directly to the Test Engineer

- The completed incident descriptions, including diagnosis and repair data
- Incident descriptions corresponding to all events defined as failures at the scoring conference with parameters categorizing failure chargeability

The dimensioning of data storage arrays must be expandable to permit the continuous addition of data as testing progresses. Data would accumulate in three categories as follows:

- The system description will change with reconfiguration, modification, or generic type replacement.
- The chronological data from the run log will continuously increase.
- Incident descriptions will be added continuously to the basic data set.

Therefore, the input format and array structure for the three data sets described must be designed to facilitate data additions.

Several processing options must be included in the computer program to meet the differing requirements for analysis of improvement-effort allocation, assessment of reliability growth, preparation of scoring conference agenda, and computation of final RAM results. Most important, the automation must have a full edit capability for revising stored data as corrections and reevaluations are made.

8.12 SCORING CONFERENCE AGENDA

Currently, the scoring conference examines the Equipment Performance Reports in exactly the order in which they were compiled. Consequently, the discussion moves from one LRU type to another in a disorderly fashion. The final recommendation of the proposed methodology is to sort the incidents by LRU type with the computer program to prepare an orderly agenda for the scoring conference. This agenda could be organized so that all the LRU types furnished by one vendor would be considered consecutively, and that vendor's representative could be invited for the appropriate sequence of the scoring conference only. All incidents relating to one LRU type would be discussed in the order of their occurrence but separately from those relating to another LRU type.

CHAPTER NINE

CONCLUSIONS

This chapter presents the findings of the quantitative analysis of the incident data and chronological run log data.

9.1 THE LINE REPLACEABLE UNITS

Table 9-1 lists all the Line Replaceable Units of the TACELIS system for which records of incident data were kept during the period of developmental testing covered by this report. During this period the system was not deployed at full-equipment strength as described in Chapter One. The major assemblies tested were:

- 1 Control and Processing Center
- 2 Remote Master Stations
- 4 Remote Slave Stations

Table 9-1 shows the numbers of units of each type that were included in the major assemblies. Each unit type is categorized as GFE or CFE where this information is available. MTBF and MTTR are given for each unit type for which incident data were available. The symmetrical 80 percent confidence limits for these MTBF and MTTR estimates are also included in Table 9-1. A reliability value for a mission time of 24 hours is given with each unit type.

For several unit types, no failures occurred during developmental testing. For these unit types, the total number of part-hours calculated according to the methods presented in Chapter Three has been recorded in place of the MTBF value. The 24-hour mission reliability for these units has been included in all computations as unity. Neither an MTTR value nor any confidence limits are given for these units.

For some units, incident data were reported, but not the subsequent repair data. For these units, MTTR and the upper and lower confidence limits on the MTTR estimate are omitted.

Table 9-1. RAM RESULTS FOR THE LINE REPLACEABLE UNITS OF THE TACELIS SYSTEM

Line Replaceable Unit	Number of Parts in Each Section							Equipment Procurement	Mean Time Between Failures			Mean Time To Repair			24-Hour Reliability
	CPC	RMS1	RMS2	RSSD	RSSE	RSSF	RSSG		Lower Confidence	Actual	Upper Confidence	Lower Confidence	Actual	Upper Confidence	
MX-9860 ACM	1	-	-	-	-	-	-	CFE		6408.0*					1.0
MX-9261 ADUA	3	-	-	-	-	-	-	GFE	8349.	19224.0	182200		**		0.99875
M-9262 ADUB	3	-	-	-	-	-	-	GFE	4943.	9612.0	36140		**		0.99751
Antenna LOB	-	-	-	1	1	1	1	CFE	1275.	2038.2	4189.		**		0.98829
ARC-134 RAD	1	-	-	-	-	-	-	GFE	2783.	6408.0	60740		**		0.99626
ARC-34 J/B	1	-	-	-	-	-	-	GFE		6408.0*					1.0
ARC-150 RAD	-	2	2	6	6	6	6	GFE	4880.	6675.2	10040	0.99	1.58	3.25	0.99641
MX-9778 ASDU	-	1	1	-	-	-	-	CFE		12816.0*					1.0
SA-1879 ASM1	11	1	1	-	-	-	-	GFE	36190	83304.0	789600	2.35	5.40	51.2	0.99971
ASM J/B	3	-	-	-	-	-	-	GFE		19224.0*					1.0
SA-1920 ASM2	3	-	-	-	-	-	-	GFE		19224.0*					1.0
ASM-2 J/B	1	-	-	-	-	-	-	GFE		6408.0*					1.0
AS-3231 ANT	-	-	-	1	1	1	1	CFE		10191.0*					1.0
CMTU	1	-	-	-	-	-	-	GFE	2050.	2136.0	21950	1.74	4.00	37.9	0.98883
CMTU CONT PN	1	-	-	-	-	-	-	CFE		6408.0*					1.0
SB-3861 CBP	1	4	4	1	1	1	1	GFE		67863.0*					1.0
SB-3862 CBP	-	1	1	-	-	-	-	GFE		12816.0*					1.0
SB-3863 CBP	-	1	1	-	-	-	-	GFE		12816.0*					1.0
SB-3928 CBP	-	-	-	1	1	1	1	GFE		10191.0*					1.0
CV-425 CTTYT	2	2	2	-	-	-	-	GFE		38448.0*					1.0
CEFLAN MCU	1	-	-	-	-	-	-	GFE		6408.0*					1.0
CEFLAN CRD	1	-	-	-	-	-	-	GFE		6408.0*					1.0
CONRAC CRT D	22	-	-	-	-	-	-	CFE	36250	70488.0	265000	1.35	3.10	29.4	0.99966
401-3 CRT DC	22	-	-	-	-	-	-	CFE	2650.	3999.5	3456.	2.99	3.41	3.97	0.99203
COM STA J/B	-	1	1	-	-	-	-	CFE		12816.0*					1.0
DMUX CONT U	1	-	-	-	-	-	-	CFE		6408.0*					1.0
PCM DEMUX	-	2	2	-	-	-	-	CFE		25632.0*					1.0
TD-1158 TP A	-	1	1	-	-	-	-	CFE		12816.0*					1.0
SN-500/U DDS	-	2	2	-	-	-	-	CFE		25632.0*					1.0
C-1005/U DP	-	-	-	1	1	1	1	CFE	4426.	10191.0	96590		**		0.99765
TDF-225/400	-	-	-	3	3	3	3	CFE	7862.	15286.5	57480		**		0.99843
3202 Disk CT	2	-	-	-	-	-	-	GFE	5568.	12816.0	121500	2.61	6.00	56.9	0.99813
9762/9877 DD	1	-	-	-	-	-	-	CFE		6408.0*					1.0
9262/2 DD	1	-	-	-	-	-	-	CFE		6408.0*					1.0
CDC-9740 DD	2	-	-	-	-	-	-	GFE		12816.0*					1.0
400Hz DT F/B	3	-	-	-	-	-	-	CFE	8347.	19224.0	182200	1.13	2.60	24.6	0.99875
LMF-1857 EMI	1	-	-	1	1	1	1	CFE	7210.	16599.0	157300		**		0.99856
Fault MON CP	1	-	-	-	-	-	-	CFE	2783.	6408.0	60740		**		0.99626
F-1406 ARFU	-	1	1	-	-	-	-	CFE	5568.	12816.0	121500	1.74	4.00	37.9	0.99813
S-1430 NTH F	-	-	-	1	1	1	1	CFE		10191.0*					1.0
50-60Hz DF/B	23	-	-	-	-	-	-	CFE		147384.0*					1.0
FBP	22	-	-	-	-	-	-	GFE	6675.	8811.0	12960	1.11	1.51	2.23	0.99728
AM-4316	-	-	-	-	-	-	-	GFE		***					
AM-4317	-	-	-	-	-	-	-	GFE		***					
AM-4318	-	1	1	-	-	-	-	GFE		12816.0*					1.0

*Part test-life hours shown, no recorded failures.
**Failures occurred but no known repair time.
***Part not used.

(continued)

Table 9-1. (continued)

Line Replaceable Unit	Number of Parts in Each Section							Equipment Procurement	Mean Time Between Failures			Mean Time To Repair			24-Hour Reliability
	CPC	RMS1	RMS2	RSSD	RSSE	RSSF	RSSG		Lower Confidence	Actual	Upper Confidence	Lower Confidence	Actual	Upper Confidence	
AM-4320	-	-	-	-	-	-	-	GFE		***					
AM-4321	-	-	-	-	-	-	-	GFE		***					
AM-4322	-	1	1	-	-	-	-	GFE		12816.0*					1.0
R-1329	-	2	2	-	-	-	-	GFE		25632.0*					1.0
RT-773	-	2	2	-	-	-	-	GFE		25632.0*					1.0
T-983	-	2	2	-	-	-	-	GFE	11130	25632.0	242900	0.52	1.20	11.4	0.99906
AM-3349	-	1	1	1	1	1	1	GFE	2185.	3286.7	5907.		**		0.99272
RT-662	-	1	1	1	1	1	1	GFE	2185.	3286.7	5907.	0.87	2.00	19.0	0.99272
Georator	-	1	1	1	1	1	1	GFE	4323.	7669.0	20880	5.21	12.00	114.	0.99688
R-1467	3	2	2	-	-	-	-	GFE	5610.	8971.2	18440	1.24	1.98	4.07	0.99733
T-1054	3	2	2	-	-	-	-	GFE	4260.	6408.0	11520	0.82	1.23	2.21	0.99626
T-4763	-	1	1	-	-	-	-	GFE		12816.0*					1.0
ICU MAINT PN	1	-	-	-	-	-	-	GFE		6408.0*					1.0
ICU PROCESSR	1	-	-	-	-	-	-	GFE		6408.0*					1.0
ICU EXPN U	1	-	-	-	-	-	-	GFE		6408.0*					1.0
LS-631 ICU	22	-	-	-	-	-	-	CFE	13390	20139.4	36190	2.23	3.44	6.55	0.99881
KG-30 J/B	-	-	-	1	1	1	1	GFE		10191.0*					1.0
KG-30 ENCRPT	9	6	6	3	3	3	3	GFE	71700	165141.0	1565000		**		0.99985
KYBD ALPHANC	22	-	-	-	-	-	-	CFE	17640	28195.2	57970	0.96	1.60	3.67	0.99915
Link MON T/B	1	-	-	-	-	-	-	CFE		6408.0*					1.0
Manual MD IU	1	-	-	-	-	-	-	CFE		6408.0*					1.0
MX-9263 MAU	4	-	-	-	-	-	-	GFE	4814.	8544.0	23260		**		0.99719
MX-9681/U MS	1	-	-	-	-	-	-	CFE		6408.0*					1.0
Modem NB DD	-	-	-	1	1	1	1	GFE	4426.	10191.0	96590	0.96	2.20	20.9	0.99765
C-9786 MCCP	1	-	-	-	-	-	-	GFE	2783.	6408.0	60740		**		0.99626
TD-203 MUX	2	-	-	-	-	-	-	GFE	2407.	4272.0	11630	5.76	10.23	27.8	0.99440
S-2109 PMS	1	-	-	-	-	-	-	CFE	1648.	3204.0	12050	0.62	1.20	4.51	0.99254
PPR Tape RDR	1	1	1	1	1	1	1	CFE	7564.	14707.5	55300	1.54	3.00	11.3	0.99837
PCM CMMD MUX	1	-	-	-	-	-	-	CFE		6408.0*					1.0
MX-9921 PP	-	-	-	1	1	1	1	GFE		10191.0*					1.0
28-Volt PS	-	-	-	1	1	1	1	CFE		10191.0*					1.0
PP-4763 PS	1	1	1	-	-	-	-	GFE		19224.0*					1.0
PP-6905 PS	16	-	-	-	-	-	-	GFE	9739.	14646.9	26330	0.34	0.53	1.01	0.99836
PP-7321 PS	-	-	-	1	1	1	1	GFE	2620.	5095.5	19160	0.87	2.00	19.0	0.99530
GX-100-A RK	1	-	-	-	-	-	-	CFE	801.8	1281.6	2635.	3.84	6.14	12.6	0.98145
REC MUX DET	-	1	1	-	-	-	-	CFE		12816.0*					1.0
C-911/U RCM	8	-	-	-	-	-	-	GFE	4355.	6408.0	11010	2.61	3.93	7.06	0.99626
AM-6858 RF A	-	1	1	-	-	-	-	CFE	3295.	6408.0	24090	2.49	4.85	18.2	0.99626
MX-9776 RF D	-	1	1	-	-	-	-	CFE		12816.0*					1.0
MX-9777 RF D	-	1	1	-	-	-	-	CFE		12816.0*					1.0
MX-9793 RF P	-	-	-	1	1	1	1	GFE		10191.0*					1.0
MX-9794 RF P	-	-	-	1	1	1	1	GFE		10191.0					1.0
ROLM CONT P	7	1	1	1	1	1	1	GFE	4777.	6786.3	10910	1.11	1.85	4.24	0.99647
ROLM CPU	6	-	-	-	-	-	-	GFE	3652.	5492.6	9872.	5.78	8.69	15.6	0.99564
ROLM CPU E C	7	-	-	-	-	-	-	GFE	19480	44856.0	425200	1.00	2.30	21.8	0.99947

(continued)

Table 9-1. (continued)

Line Replaceable Unit	Number of Parts in Each Section							Equipment Procurement	Mean Time Between Failures			Mean Time To Repair			24 Hour Reliability
	CPC	RMS1	RMS2	RSSD	RSSE	RSSF	RSSG		Lower Confidence	Actual	Upper Confidence	Lower Confidence	Actual	Upper Confidence	
ROLM Data LC	1	1	1	1	1	1	1	GFE	3679.	5883.0	12090	3.28	5.24	10.8	0.99593
ROLM DLC J/B	-	1	1	-	-	-	-	GFE		12816.0*					1.0
ROLM MEM CHS	3	1	1	1	1	1	1	GFE	10860	21115.5	79400	2.65	5.15	19.4	0.99886
ROLM I/O CHS	6	1	1	1	1	1	1	GFE	26690	61455.0	582600		**		0.99961
ROLM ARIU	-	1	1	-	-	-	-	GFE		12816.0*					1.0
8660-B RTSG	-	1	1	-	-	-	-	CFE	5568.	12816.0	121500	0.17	0.40	3.79	0.99813
C-9112 SCP	11	-	-	-	-	-	-	GFE	3008.	3916.0	5608.	1.14	1.48	2.12	0.99389
SEACS DD	2	-	-	-	-	-	-	CFE		12816.0*					1.0
SEACS PS & SF	2	-	-	-	-	-	-	CFE		12816.0*					1.0
SEACS D C	2	-	-	-	-	-	-	CFE		12816.0*					1.0
C-9785 SCCP	5	-	-	-	-	-	-	GFE		32040.0*					1.0
MX-9819 SCU	-	1	1	1	1	1	1	CFE	4321.	7669.0	20880	0.87	2.00	19.0	0.99688
MX-9717 TBIU	-	1	1	-	-	-	-	CFE		12816.0*					1.0
TACJAM C P	2	-	-	-	-	-	-	CFE	3295.	6408.0	12050		**		0.99626
TD-1099 TDDM	2	-	-	-	-	-	-	GFE	2407.	4272.0	11630	0.75	1.33	3.62	0.99440
TD-1098 TDM	1	1	1	-	-	-	-	GFE	4943.	9612.0	36140	3.34	6.50	24.4	0.99751
J-3326TDDMJB	1	-	-	-	-	-	-	CFE		6408.0*					1.0
RD-369/441	32	-	-	-	-	-	-	GFE	608.1	638.8	672.8	2.62	2.76	2.91	0.96313
TS-3530TSRTP	1	-	-	-	-	-	-	CFE		6408.0*					1.0
C-9886 TCM	-	1	1	-	-	-	-	CFE	5568.	12816.0	121500	0.39	0.90	8.53	0.99813
TS-3529 TF	1	-	-	-	-	-	-	CFE	2783.	6408.0	60740	0.09	0.20	1.90	0.99626
TD-1691 TCG	2	-	-	-	-	-	-	GFE		12816.0*					1.0
TNH-20 PSR	1	-	-	-	-	-	-	GFE		6408.0*					1.0
AM-6858 AMP	-	1	1	-	-	-	-	CFE		12816.0*					1.0
CV-3169 OEM	1	4	4	-	-	-	-	GFE	2060.	2621.5	3605.	4.59	5.53	6.98	0.99089
CV-3170 ODM	8	-	-	-	-	-	-	GFE	1908.	2441.1	3387.	6.19	7.56	9.70	0.99022
IP-1157 PDU	6	-	-	-	-	-	-	GFE	9883.	19224.0	72260		**		0.99875
MX-9428 PPU	-	5	5	-	-	-	-	GFE	3380.	4577.1	6770.	3.84	5.20	7.69	0.99477
C-9376 RCU	7	1	1	-	-	-	-	GFE	4438.	6408.0	10610	3.48	5.03	8.33	0.99626
PAN PROC J/B	-	1	1	-	-	-	-	GFE		12816.0*					1.0
R-1849 HF RC	-	2	2	-	-	-	-	GFE	11130	25632.0	242900		**		0.99906
R-1850 VHF R	-	15	15	-	-	-	-	CFE	3587.	4272.0	5279.	6.50	7.40	8.59	0.99440
R-1982 TCR	-	-	-	1	1	1	1	GFE	1526.	2547.8	5843.	5.73	10.17	27.7	0.99062
MAGN Tape D	2	-	-	-	-	-	-	GFE	1217.	1830.9	3291.	0.77	1.16	2.08	0.98698
MAGN Tape CT	2	-	-	-	-	-	-	GFE		12816.0*					1.0
MAGN Tape CB	1	-	-	-	-	-	-	GFE		6408.0*					1.0
MY-8450 ADPT	1	-	-	-	-	-	-	GFE		6408.0*					1.0
Central PROC	2	-	-	-	-	-	-	GFE	3295.	6408.0	24090	1.29	2.50	9.40	0.99626
C-84080 CONT	1	-	-	-	-	-	-	GFE	2783.	6408.0	60740	3.47	8.00	75.8	0.99626
AN/UYK-7 CMU	5	-	-	-	-	-	-	GFE		32040.0*					1.0
AN/UYK-7 EC	3	-	-	-	-	-	-	GFE		19224.0*					1.0
AN/UYK-7 PM	5	-	-	-	-	-	-	GFE	6017.	10680.0	29070	0.86	2.67	7.27	0.99776
PP-6258 PS	3	-	-	-	-	-	-	GFE	8347.	19224.0	182200	0.78	1.80	17.1	0.99875
WBDL T/B	1	-	-	-	-	-	-	GFE		6408.0*					1.0

9.2 THE MAJOR ASSEMBLIES

The lack of complete maintenance data precludes the computation of *achieved availability* or *maintainability* for the assemblies of the TACELIS system. Therefore, *inherent availability* and *repairability* have been reported instead. Table 9-2 lists the *reliability, inherent availability,* and *repairability* for the major assemblies of TACELIS. These data are based on the chronological run logs for the reported phase of TACELIS developmental testing. Almost all of the up-to-down assembly state transitions were software-induced.

Table 9-2. MAJOR ASSEMBLY STATISTICS

Assembly	Reliability for One-Hour Mission Time	Inherent Availability	Repairability for One-Hour Corrective Maintenance Time
CPC	.724	.893	.933
RMS	.574	.747	.806
RSS	.535	.615	.999

Notice that even when reliability values for a system are low, system inherent availability values may be reasonable because repairability values are close to unity.

9.3 THE TOTAL SYSTEM

A unique table of RAM statistics cannot be given for the total TACELIS system since the reliability of the total system is different for each possible system configuration. However, it is apparent from Table 5-1 (Chapter Five) that the RSS assembly has the lowest MTBF value and the largest MTTR value of the three assembly types constituting the TACELIS system. Correspondingly, the RSS has the lowest assembly availability, as shown in Table 9-2. Moreover, at least two RSSs must remain functional to obtain Line of Bearing information. An analysis of the essential assemblies for minimum TACELIS operation -- 1 CPC, 1 RMS, and 2 RSSs -- reveals that the RSS is the "weakest link in the chain".

9.4 REPORTED INCIDENTS

The greatest number of incidents were reported for GFE unit types. Table 9-3 lists the 10 LRU types requiring the greatest number of maintenance actions.

Table 9-3. UNIT TYPES GENERATING MOST INCIDENT REPORTS

Unit Type	Number of Incidents	Equipment Procurement
Temporary Storage Recorder	321	GFE
CRT Display Controller	47	CFE
VHF Receiver 1850	45	GFE
Output Encoder Module	22	GFE
Output Decoder Module	21	GFE
Scanner Control Panel	18	GFE
Function Button Panel	16	GFE
Pan Processor Unit	14	GFE
ARC-150 Radio	13	GFE
ROLM Control Panel	10	GFE

9.5 THREE UNITS MOST CRITICAL TO SYSTEM HARDWARE RELIABILITY

The three unit types having the greatest impact on system hardware reliability as identified from the available developmental test data in Section 7.2 (Chapter Seven) are:

- The LOB antenna in the RSS
- The Twin-Channel Receiver in the RSS
- The RAMTEK Keyboard in the CPC

9.6 ASSEMBLY HARDWARE RELIABILITY

The 24-hour reliabilities of the LRUs can be used to calculate the hardware reliabilities of the TACELIS major assemblies. The reliability equations in Chapter Four, which represent the reliability block diagrams of the CPC, RMS, and RSS (Figures 4-1, 4-2, and 4-3, respectively) can be solved by using the LRU 24-hour reliabilities shown in Table 9-1. Table 9-4 shows the 24-hour hardware reliabilities of the major assemblies.

Table 9-4. MAJOR ASSEMBLY 24-HOUR HARDWARE RELIABILITIES	
Assembly	Reliability
CPC	
Manual Mode	0.98019
SEACS Mode	0.94628
RMS	0.96449
With RSS Control	0.96297
RSS	0.97202
With LOB Function	0.94493

9.7 IMPACT OF SOFTWARE-INDUCED ASSEMBLY FAILURE

The following results are obtained when 24-hour first-level capability assembly reliabilities for hardware only are compared with similar values based on hardware and software failures combined:

Assembly	24-Hour Hardware Reliability	24-Hour Hardware/ Software Reliability
CPC	.94628	.00043
RMS	.96297	.00000(16)
RSS	.94493	.00000(03)

Recommendations for improvement of these values are presented in Chapter Ten.

CHAPTER TEN

RECOMMENDATIONS

This chapter presents suggestions for improvement-effort allocation made on the basis of the conclusions reported in Chapter Nine.

10.1 SYSTEM CONFIGURATION

The major assembly that is most detrimental to TACELIS system reliability is the Remote Slave Station. Two corrective activities are recommended:

- The RSS must be the focus of a concentrated software improvement effort.
- The TACELIS system should be deployed wherever possible with redundant RSS configuration. The optimum interface for four RSSs in one RMS branch is

$$\begin{tikzcd}[row sep=small] & & & \mathrm{RSS} \arrow[r, dash] & \mathrm{RSS} \\ \mathrm{CPC} \arrow[r, dash] & \mathrm{RMS} \arrow[r, dash] & \mathrm{MRSS} \arrow[ur, dash] \arrow[dr, dash] & & \\ & & & \mathrm{RSS} & \end{tikzcd}$$

10.2 LOGISTIC SUPPORT

The unit types identified in Section 9.4 as having generated the greatest numbers of maintenance requests will (with the present failure rates) have a severe impact on the maintenance and supply procedures for the TACELIS system. For these unit types, a study should be conducted to choose among alternative solutions, including:

- Modification and improvement of unit
- Implementation of redundancy
- Stocking of spares
- Replacement of unit type

10.3 HARDWARE IMPROVEMENT ALLOCATION

The hardware improvement effort should be directed toward three unit types:

- The LOB antenna in the RSS
- The Twin-Channel Receiver in the RSS
- The RAMTEK Keyboard in the CPC

The currently suggested improvement effort is based on the limited data made available for this study and on the definitions of system success outlined in Chapter Four. Subsequent reevaluation with more data and analysis resulting from additional testing may alter this recommendation.

10.4 SOFTWARE IMPROVEMENT

Software is the major reliability problem for TACELIS at the present stage of development. The scope of this evaluation did not provide for an assessment of software reliability improvement or performance prediction. It is recommended that a software reliability assessment effort be introduced as part of RAM analysis during the operational testing of TACELIS. Planning for software data collection and analysis should begin as soon as possible because the collection of useful software incident data requires appropriate data forms and instruction in their use. The selection of forms and training in the use of these forms could begin in the present development test program.

10.5 LIMITATIONS OF DATA

The results presented in this report are based on the information available to ARINC Research for this study. This information (data from the first 11 months of developmental testing of the TACELIS system) is incomplete at the present time. The reader must be aware that the conclusions and recommendations presented are subject to change as the following events take place:

- More detailed data become available.
- Existing data are reinterpreted.
- Definitions of system success are changed.
- Additional system testing is conducted.

Methodologies for analyzing the data have been developed. The possibilities and limitations of the test procedures currently in use have been identified. A preliminary first estimate of numerical results based on early data returns has been made. This report, if used with an understanding of the deficiencies in the data base from which it was developed, should be a useful guide to planning for the future of the TACELIS materiel development process.